THE ELEMENTARY PRINCIPLES OF GRAPHIC STATICS

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The Elementary Principles of Graphic Statics

SPECIALLY PREPARED FOR STUDENTS OF SCIENCE AND TECHNICAL SCHOOLS, AND THOSE ENTERING FOR THE EXAMINATIONS OF THE BOARD OF EDUCATION IN BUILDING CONSTRUCTION, MACHINE CONSTRUCTION, DRAWING, APPLIED MECHANICS, AND FOR OTHER SIMILAR EXAMINATIONS

BY

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PREFACE

THE following chapters are placed before students of Building Construction, Applied Mechanics, and Machine Construction and Drawing, in the hope that they may be of service to those who desire aid in the study of the "Statics" branch of these subjects.

It should be stated that, in the chapter on Graphic Arithmetic, only such matter has been introduced as is deemed necessary for the study of the succeeding chapters.

The author desires to express his gratitude to Professor Henry Adams, M.I.C.E., M.I.M.E., F.S.I., etc., for his kindness in reading through the MS., and for his valuable help and advice.

EDWARD HARDY.

SAXATILE, MERTHYR TYDFIL,
December, 1903.

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CHAPTER I

Graphic Arithmetic

CHAPTER I

GRAPHIC ARITHMETIC

1. In ordinary arithmetic a number (unity) is chosen, and all quantities expressed in multiples of that number: thus, 5 means that unity is taken 5 times, and 4·5 means that unity is taken 4·5 times.

Calculations are then made arithmetically.

2. Instead of expressing unity by a figure we can express it by a line. All other quantities are then represented by lines whose lengths are proportional to the magnitudes they represent.

Let a line $\frac{1}{2}''$ long represent unity, then 5 would be expressed by a line five times as long, and 4·5 would be expressed by a line four and one-half times as long. Again, let a line $\frac{3}{4}''$ long represent one article (or 1 yd., 1 hr., etc.), then 12 articles (or 12 yds., 12 hrs., etc.) would be shown by a line twelve times as long, i.e. by a $9''$ line.

It will thus be seen that, after having decided upon a unit length, any quantity, whether abstract or concrete, can be expressed by lines.

When the quantities are represented by lines, the calculations are made by means of geometrical drawings, i.e. "graphically."

3. This work, being intended for students who are

already familiar with geometry, it is assumed that scale drawing is understood.

A rule, with all the divisions continued to the edge and with the inch and the subdivisions of the inch ($\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{3}{8}$, etc.) being divided into tenths, will be found the most convenient. An ordinary flat rule marked on both faces would contain 8 such scales, while a triangular one would contain 12.

The measurements should be transferred to the paper (or read off) by applying the edge of the rule directly to the line, and not with the dividers.

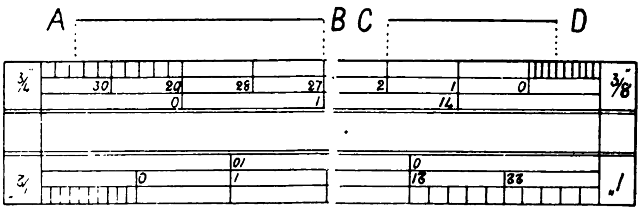


FIG. 1.

4. The numbers 1, 2, 3, etc., can also be read as 10, 20, 30, etc., when the tenths will become units and the hundredths will become tenths. In a similar way they may be read as hundreds, thousands, etc.

For example see Fig. 1, where :—

if $\frac{3}{4}'' = 1$ unit, then $AB = 1{\cdot}75$ units
,, $\frac{3}{4}'' = 10$ units, then $AB = 17{\cdot}5$,,
,, $\frac{3}{4}'' = 100$,, ,, $AB = 175{\cdot}$,,
,, $\frac{3}{4}'' = 1000$,, ,, $AB = 1750{\cdot}$,,

and, if $\frac{3}{8}'' = 1$ yd., 1 lb., etc., then $CD = 2{\cdot}4$ yds., lbs., etc.
,, ,, $\frac{3}{8}'' = 10$ yds., lbs., etc., ,, $CD = 24$,, ,, ,,
,, ,, $\frac{3}{8}'' = 100$,, ,, ,, ,, $CD = 240{\cdot}$,, ,, ,,
,, ,, $\frac{3}{8}'' = 1000$,, ,, ,, ,, $CD = 2400$,, ,, ,,

5. Sometimes the unit is given by means of a line whose length is not stated. In order to find the numerical value of a line when the unit is given thus, it is advisable to divide the unit line into tenths, plot off as many units as possible, and state the remaining portion (if any) as decimals.

Let A be a line whose magnitude is required, and B the unit line.

Divide B into tenths.

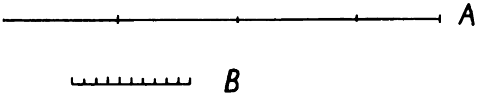


FIG. 2.

It will be seen that B can be plotted 3 times along A, and the remaining portion of A is equal to 7 tenths of B.

A, therefore, represents 3·7 units.

6. ADDITION.—Let it be required to add 1·7 yds. to 1·35 yds.

Take any convenient scale, as $1'' = 1$ yard. Set off $A B$ (Fig. 3) $= 1{\cdot}7$, and adjoining this, and in a straight line with it, set off $B C = 1{\cdot}35$.

FIG. 3.

It is now evident that $A C$ equals the sum of $A B$ and $B C$, and, by applying the scale to it, it is found to be 3·05, i.e. the sum $= 3{\cdot}05$ yds.

7. Find the sum of 5·4 tons, 4·7 tons, and 3·2 tons. Adopt a scale—say $\frac{1}{4}'' = 1$ ton. Set off $A B$, $B C$

and $C D$ (Fig. 4) in a straight line, and equal to 5·4, 4·7 and 3·2 respectively. Then $A D =$ their sum, and,

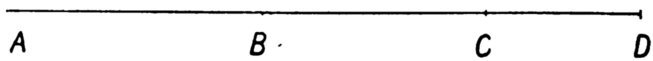


FIG. 4.

if measured, will be found to represent 13·3 tons.

8. SUBTRACTION.—Take 42·5 lbs. from 73 lbs.

FIG. 5.

Let the scale be $\frac{1}{2}''$ = 10 lbs. Draw $A B =$ 73 lbs. (Fig. 5), and from B set back along $B A$, $B C =$ 42·5 lbs. $A C$ is now the remainder, and by measurement this is seen to represent 30·5 lbs.

9. It should be noted that all positive numbers, or plus values, are set off in one direction, usually from left to right, while the negative numbers, or minus values, are measured back in the opposite direction.

10. *Example.*—Simplify (37 − 42 − 3 + 41) tons.

Take a scale such as $\frac{3}{4}''$ = 10 tons.

Commencing at the point A, measure off $A B =$ 37 tons to the right, as in Fig. 6. From B mark off $B C$ = 42 tons, but, since the 42 tons are to be subtracted, $B C$ must be taken in the opposite direction to $A B$. From C measure $C D =$ 3 tons. This again being negative, it must be taken in the same direction as $B C$. From D measure $D E =$ 41 tons. This being positive, it must be taken in the same direction as $A B$.

FIG. 6.

The distance from A to E (i.e. the first and last points) will give the answer. In the example given it will be noticed that the point E comes on that side of A towards which the positive quantities were taken, therefore $A\,E$ is positive. If E had come on the other side of A, then the answer would have been negative.

11. SIMILAR TRIANGLES.—Before proceeding to multiplication and division, it is necessary to study the relationship between similar triangles. Similar triangles are those whose angles are equal, each to each—i.e., if the two triangles $A\,B\,C$ and $D\,E\,F$ (Fig. 7) be similar, the angle $A\,B\,C$ is equal to the angle $D\,E\,F$; the angle $B\,A\,C =$ the angle $E\,D\,F$; and the angle $A\,C\,B =$ the angle $E\,F\,D$.

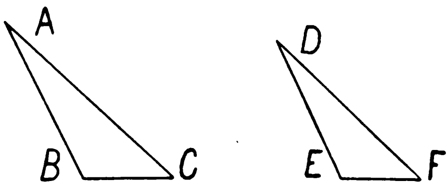


FIG. 7.

If two angles of one triangle be equal to the two angles of another triangle, each to each, then, since the three angles of every triangle $= 180°$, the third angle of the one is equal to the third angle of the other, and the triangles are similar in every respect.

The particular point to be noted concerning similar triangles is that the sides of the one bear the same relation to each other as do the sides of the other triangle, each to each; that is, if $A\,B$ (Fig. 7) be twice $B\,C$, then $D\,E$ is twice $E\,F$; or, if $A\,C$ be $1\frac{1}{2}$ times $A\,B$, then $D\,F$ is $1\frac{1}{2}$ times $D\,E$.

This comparison is true of any two sides, providing the sides chosen in the one triangle correspond with those chosen in the other.

12. It is also true if the perpendicular height be taken

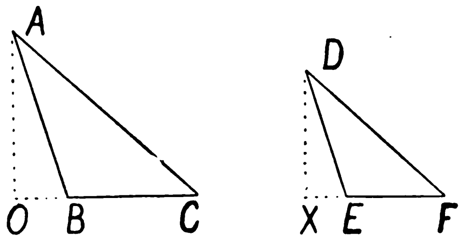


FIG. 8.

as a side, because it can easily be shown that the triangle $A\,O\,C$ (Fig. 8) is similar to the triangle $D\,X\,F$, or that the triangle $A\,O\,B$ is similar to the triangle $D\,X\,E$.

13. The relationship between the sides of similar triangles is generally expressed as follows :—

$A\,B$ is to $B\,C$ as $D\,E$ is to $E\,F$ (see Fig. 7), and written $A\,B : B\,C :: D\,E : E\,F$.

But this is proportion, and the product of the extremes is equal to the product of the means :

$$\text{therefore } A\,B \times E\,F = B\,C \times D\,E,$$

$$\text{and } A\,B = \frac{B\,C \times D\,E}{E\,F}$$

Similarly any one side can be found in terms of the others.

14. Multiplication, Division and Proportion can each be worked by means of similar triangles.

MULTIPLICATION.—Let it be required to find a line 2·3 times as long as a given line A.

Take a scale such as $1'' = 1$ unit. Draw $B\,C = 1$ unit, and $B\,D = 2{\cdot}3$ units (Fig. 9).

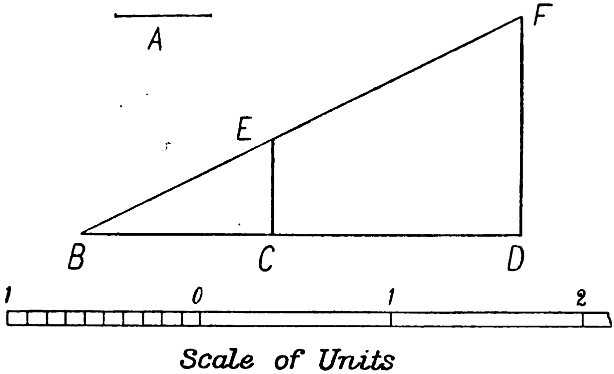


FIG. 9.

From C erect a perpendicular $C\,E$ equal to the given line A. Join $B\,E$ and produce it until it meets a perpendicular from D at F.

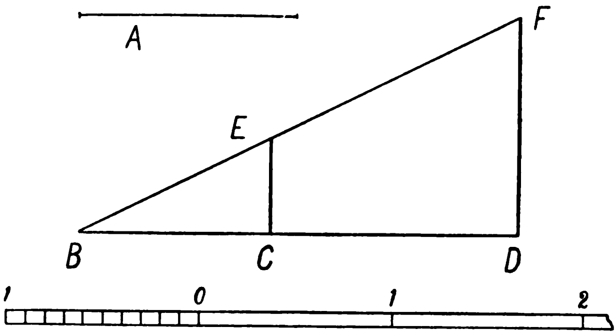
Then $D\,F = 2{\cdot}3$ times $C\,E$ or $2{\cdot}3$ times as long as the given line A.

15. DIVISION.—Divide a given line A by $2{\cdot}3$.

Draw a line $B\,C = 1$ unit, and $B\,D = 2{\cdot}3$ units (Fig. 10). From D erect a perpendicular $D\,F$ equal to the given line A. Join $B\,F$, and from C erect the perpendicular $C\,E$, meeting it at E.

Then $C\,E$ represents the quotient of $D\,F$, or A divided by $2{\cdot}3$.

16. *Proofs.*—Since the triangles $E\,B\,C$ and $F\,B\,D$ (Figs. 9 and 10) have the angle $F\,B\,D$ common to both, and the angle $E\,C\,B =$ the angle $F\,D\,B$, both being right angles, then the two triangles are similar in every respect (§ 11).



Scale of Units

FIG. 10.

Therefore $DF : BD :: CE : BC$

and $DF = \dfrac{CE \times BD}{BC}$, (1)

also $CE = \dfrac{DF \times BC}{BD}$. (2)

But $BC = 1$ unit and $BD = 2{\cdot}3$ units,

therefore $DF = \dfrac{CE \times 2{\cdot}3}{1} = CE \times 2{\cdot}3$,

and $CE = \dfrac{DF \times 1}{2{\cdot}3} = DF \div 2{\cdot}3$.

17. PROPORTION.—It should be noticed that multiplication and division are simply proportions where one of the quantities of the known ratio is unity.

The equations 1 and 2 are true whatever values are given to BC and BD, provided that they are properly set out to scale, so the construction for a problem in proportion is similar to that for multiplication and division.

Notes :—

1. $B\,C$ and $B\,D$ must be drawn to the same scale.
2. $D\,F$ must be measured by the same scale as that by which $C\,E$ is drawn, and *vice versa.*
3. $C\,E$ (Fig. 9) and $D\,F$ (Fig. 10) were each drawn equal to a given line, but they could have been drawn to scale equal to any known quantity.
4. A different scale may be used for $B\,C$ and $B\,D$ to that used for $C\,E$ and $D\,F$.
5. The perpendicular representing the known quantity must be erected at the end of the line shown in the denominator of the equations 1 and 2.

18. *Examples.*—Multiply 350 lbs. by 1·7.

Let the scale for the multiplicand be $\frac{3}{8}'' = 100$ lbs., and the scale for the multiplier be $2'' = 1$ unit.

By the second scale set off $A\,B = 1$ unit, and $A\,C = 1·7$ units (Fig. 11).

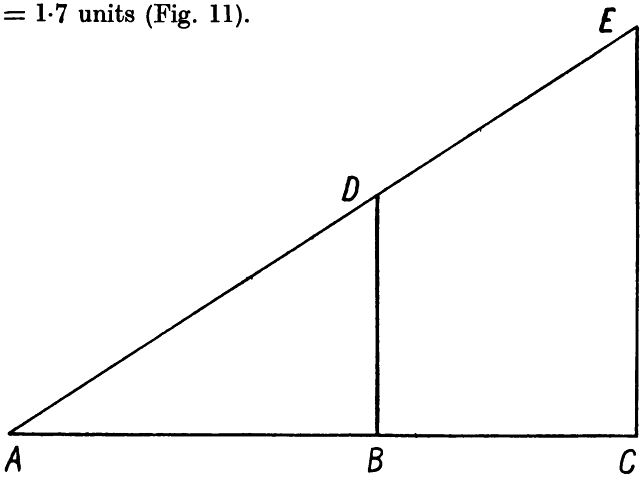


Fig. 11.

From B draw the perpendicular $B\,D = 350$ lbs. by the first scale.

Join $A\,D$, and produce it to meet the perpendicular $C\,E$. By applying the first scale, $C\,E$ will be found to represent 595 lbs.

19. Find the product of the lines A and B if the line C be the unit.

Draw $D\,E = C$, and $D\,F = B$ (Fig. 12).

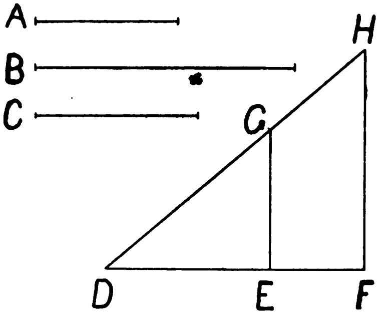


FIG. 12.

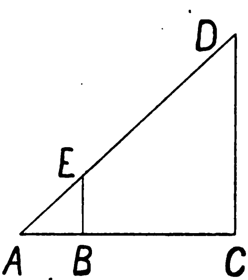


FIG. 13.

At E erect the perpendicular $E\,G = A$. Join $D\,G$, and produce it to meet the perpendicular $F\,H$ at H.

Then $F\,H$ is the product of A and B.

N.B.—The result would have been the same if $D\,F$ were made equal to A, and $E\,G$ equal to B.

20. Divide 42·5 yards by 3·4.

Make $A\,B$ and $A\,C$ equal to 1 and 3·4 units respectively. At C set up $C\,D$ equal to 42·5 yards by scale.

Join $A\,D$ and erect the perpendicular $B\,E$. $B\,E$ measured to scale gives 12·5 yards.

21. Find five-sevenths of a given line. This may be stated as a proportion, thus :

7 : 5 : : given line : required part.

therefore the required part $= \dfrac{\text{given line} \times 5}{7}$.

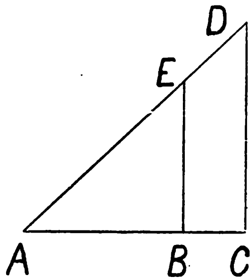


Fig. 14.

Taking a suitable scale, make $A\,B = 5$ and $A\,C = 7$ (Fig. 14). 7 is the denominator in the above equation, and it is represented by $A\,C$. Therefore from C erect the perpendicular $C\,D$ equal to the given line. Join $A\,D$, and from B erect the perpendicular $B\,E$ meeting it at E. Then $B\,E = \frac{5}{7}\,C\,D$.

22. If a rod of iron 3·2 yds. long weighs 12·6 lbs. what would be its weight if it were 7·5 yds. long?

The proportion is 3·2 yds. : 7·5 yds. : : 12·6 lbs. : x lbs.

$$\text{therefore } x = \frac{12{\cdot}6 \text{ lbs.} \times 7{\cdot}5}{3{\cdot}2}.$$

Draw $A\,B$ and $A\,C$ (Fig. 15) equal to 3·2 yds. and

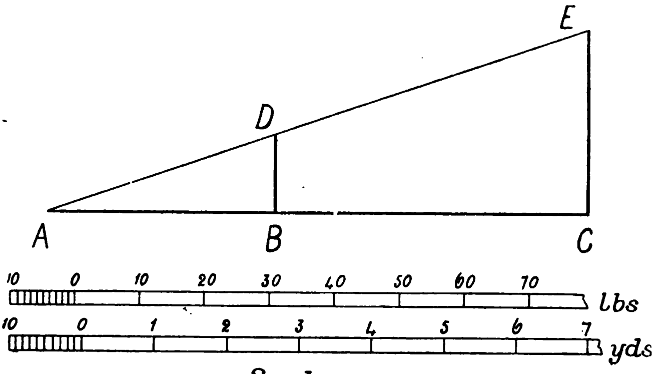


Fig. 15.

7·5 yds. respectively. From B erect the perpendicular $B D = 12{\cdot}6$ lbs. Join $A D$, and produce it until it meets the perpendicular $C E$. Then $C E = 29{\cdot}5$ lbs.

23. The preceding examples, 18 to 22, could have been solved equally well by using another diagram.

In the last exercise $x = \dfrac{12{\cdot}6 \text{ lbs.} \times 7{\cdot}5}{3{\cdot}2}$

Draw $A B$ and $A C$ (Fig. 16) equal to 3·2 and 7·5 respectively.

At A erect the perpendicular $A\ D$ equal to 12·6 lbs.

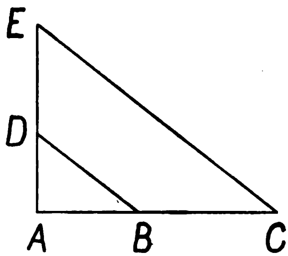


FIG. 16.

Since $A\ B$ represents the denominator in the above equation, join B to D.

From C draw $C E$ parallel to $B\ D$ until it meets the perpendicular from A at E.

Then $A\ E = x = 29{\cdot}5$ lbs.

EXAMPLES TO CHAPTER I.

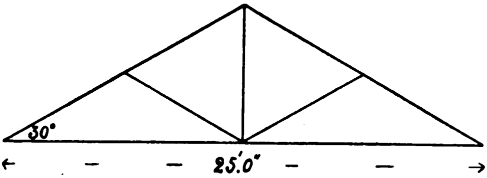
EX. CH. I.—FIG. 1.

1. What does $A\ B$ (Fig. 1) show :—
   (a) With a scale of $\frac{1}{4}'' = 1$ unit.
   (b) With a scale of $\frac{3}{8}'' = 1$ yard.
   (c) With a scale of $\frac{3}{4}'' = 1$ ton.
   (d) With a scale of $\frac{7}{16}'' = 1000$ lbs.
2. Taking a convenient scale, graphically determine the following :—
   (a) The diagonal of a square whose sides are 36 ft.

(*b*) The perpendicular height of an equilateral triangle with 15″ sides.

(*c*) The height of a wall, if a 24 ft. ladder leaning against it, with the foot 7·5 ft. from the wall, just reaches the top.

(*d*) The length of the different members in Fig. 2.

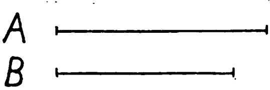


Ex. Ch. I.—Fig. 2.

3. Draw a line 2″ long, and find $\frac{5}{9}$ of it.

4. Find the sum of A and B (Fig. 3) if the unit line measures $\frac{1}{2}$″.

5. Find the product of A and B (Fig. 3) if $\frac{3}{4}'' = 1$ unit.



Ex. Ch. I.—Fig. 3.

6. Draw two lines, A 2·3 inches long, and B 1·5 inches long.

If the scale be $\frac{1}{2}'' = 1$ unit, graphically determine $\frac{A}{B} + B$.

Chapter II

FORCE

24. Force is (*a*) that which tends to move a body,
or (*b*) that which tends to stop a body when it is moving,
or (*c*) that which tends to change the direction of a body when it is moving.

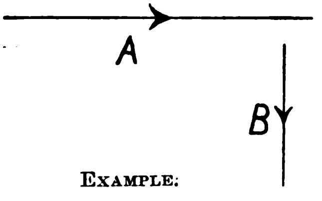
In this work it is only intended to deal with force as defined in (*a*). No reference will be made to velocity, and only bodies which are in a state of rest relatively to neighbouring bodies will be treated upon.

25. Force is measured in units of lbs., cwts., or tons.

26. We have already seen that lbs., etc., can be represented by lines drawn to scale. Hence, if the magnitude of a force be known, a line may be drawn whose length will be proportional to the force.

27. Force must be exerted in a certain direction; the line representing it must, therefore, be drawn in that direction.

28. An arrow can be placed on the line indicating *the sense of the force*, that is, showing in which direction along the line the force is acting.



Example.

Example.—If $\frac{1}{2}'' = 10$ lbs., then A represents a force $= 32$ lbs. acting from left to right, and B a downward force $= 15$ lbs.

29. The point of application (i.e. the place at which the force is applied) must be known.

30. When the magnitude, direction, sense, and point of application of a force are known, the force is said to be known.

These four points should be clearly understood, and always kept in mind. In determining a force the student must see that he finds all four.

31. Resultant.—If a number of forces (whether parallel or otherwise) act on a body, and move it in a certain direction, it is evident that another force could be found, which, acting in that direction, would do the same work.

This force is called the resultant of the others.

32. Equilibrium.—If the resultant of a number of forces be zero, then they are said to be in equilibrium. If these forces be applied to a body in a state of rest, then it will still remain at rest.

33. Equilibrant.—When a body is not in equilibrium it moves in a certain direction with a force which has a resultant. Another force equal to the resultant in magnitude, acting in the same line and opposite in sense, would produce equilibrium.

This force is called the equilibrant.

34. The equilibrant and the resultant of a system of forces are always equal in magnitude, act in the same line of direction, and are of opposite sense.

Note.—By old writers the word direction meant line of action and sense together, and in common language direction is still used in this way.

35. If a number of forces be in equilibrium, any one of them is the equilibrant of the others, and if the sense be reversed, it will represent their resultant.

For, if a system of forces be in equilibrium, each force helps to maintain it, and the removal of any one of them

would cause the remainder to move along the line on which it was acting, and in the opposite direction.

36. Parallel Forces.—Forces are said to be parallel when the lines along which they act are parallel.

Suppose forces equal to 5, 3, and 8 lbs. to be acting in one direction, and forces equal to 4, 7, and 2 lbs. in the opposite direction. In the one direction a force equal to 16 lbs. would be acting, whilst against that a force equal to 13 lbs. would be exerted. The whole system will have a resultant of 3 lbs. acting in the first direction. The 3 lbs. represents the resultant of the 6 forces, and acts in the direction of the 16 lbs.

If a force equal to 3 lbs. be added to the second set of forces, or taken from the first, then the whole system would be in equilibrium.

37. In dealing with parallel forces those acting in one direction are taken as positive, and those acting in the opposite direction as negative. The algebraical sum of all the forces will represent the resultant, and it will act in the direction of those whose sum is the greater.

38. If this sum be zero, then all the forces are in equilibrium, and, conversely, if a system of parallel forces be in equilibrium, then the algebraical sum = 0.

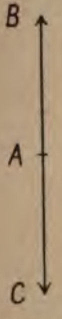


Fig. 17.

Fig. 17 represents a force *A B* acting on a point *A*. If only this force were acting on it, it would move in the direction of *A* to *B*, and to keep it in equilibrium, another force *A C* equal to *A B*, and pulling it in the opposite direction, must be introduced.

Figs. 18 and 19 show how by means of two spring balances the student can prove for

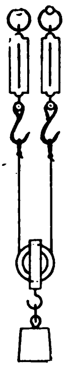


FIG. 18.

himself that the sum of all the forces acting downwards is equal to the sum of the forces supporting them. Of course, the weight of the pulley (Fig. 18) or the bar (Fig. 19) must be added, as it exerts a downward pressure.

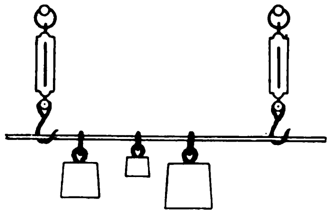


FIG. 19.

Fig. 20 represents a beam carrying three loads. On examination it will be seen that the two walls act in just the same way as the balances in Fig. 19. Hence the force exerted by the two walls together must equal the sum of all the forces acting downwards, together with the weight of the beam.

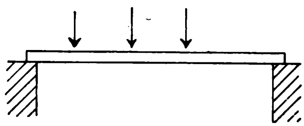


FIG. 20.

39. REACTION.—When a force acts on a body it produces a resisting force from that body. This second force is always equal to and opposite to the first.

The beam with its load (Fig. 20) exerts a force on the walls, and this produces a resistance from each wall equal to the portion of the weight it has to carry. These resistances are called the reactions of the wall.

40. MOMENTS.—It now becomes necessary to ascertain why the point of application of a force should be known. Place a book or similar object at $A B C D$ (Fig. 21) on a table. Apply a force, as shown at P. This will cause the book to rotate clockwise, i.e. in

the same direction as the hands of a clock. If the force be applied near A, it will rotate in the opposite direction, or anti-clockwise. By applying the force at different points, the student will find that to move the book forward he must apply a force in a direction which, if produced, would pass through the point G.

Again, let him take a lath, holding it horizontally by one end. Place a 1 lb. weight 1 ft. from the hand. He will find that the weight causes the lath to try to rotate with his hand as the centre of rotation, and he also experiences a difficulty in counteracting this rotation. If he moves the weight 2 ft. from the hand, he will find the tendency to rotate twice as great, and that it is twice as difficult to keep the weight in position.

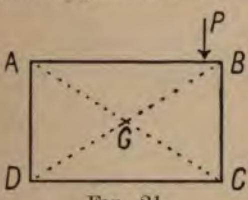


FIG. 21.

41. From this it will be seen that the greater the distance the weight or force is from a certain point, the greater is its tendency to produce rotation round that point.

42. This tendency of a force to produce rotation is called the Moment of the force, or Bending Moment.

43. If a force passes through the point chosen, and the point is supported, the force cannot produce rotation, hence there is no Moment. It acts simply as a force.

44. Referring again to the weight supported on the lath 2 ft. from the hand, it is wrong to say that the strain on the hand is 2 lbs. because only 1 lb. is supported. How, then, shall the moment be measured? It is now clear that it will depend directly upon the magnitude of the force, and upon the perpendicular

distance of the line of action of the force from the point on which it is supposed to rotate.

Hence, in the last example the strain on the hand is 1 lb. × 2 ft. = 2 ft.-lbs.

As before explained, the unit of force is generally expressed in lbs., cwts., or tons, and the unit of length in inches or feet, so the moment of a force would be expressed as — inch-lbs., ft.-lbs., ft.-cwts., etc.

45. The moment of a force which produces clockwise rotation is generally taken as negative, and that producing rotation in the opposite direction as positive.

We will now proceed to find the moments in an example. The student should again use his spring-balances, and arrange them as in Fig. 22. To prevent the arrangement being cumbersome, he can take an inch for his unit of length and mark off the inches on the bar.

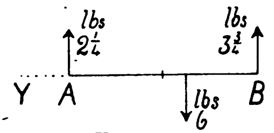


Fig. 22.

In the example shown the bar is 8″, and the weight, which is 6 lbs., is shown 3″ from one end. The balance nearer the weight now registers 3¾ lbs., and the other 2¼ lbs.

The system shows three parallel forces in equilibrium, and the force acting downwards is equal to the sum of those acting in the opposite direction.

Any point can now be selected, and the moments of all the forces about that point ascertained, care being taken to prefix the + (plus) or − (minus) signs, as already explained.

First let the centre of the beam be taken as the point.

This must now be considered as a pivot on which the beam can turn.

The 6 lbs. would cause it to turn clockwise, and is 1″ from the point, so the moment is $-$ 6 inch-lbs.

The $3\frac{3}{4}$ lbs. would cause it to revolve in the opposite direction, and is 4″ from the point, so the moment is + 15 inch-lbs.

The $2\frac{1}{4}$ lbs. is 4″ away, and would cause clockwise motion, so the moment is $-$ 9 inch-lbs.

The algebraical sum of the moments of all the forces about this point is $(-6+15-9)$ inch-lbs. = o.

Take the point *y* 2″ from *A* as shown (Fig. 15).

The moments are + ($2\frac{1}{4}$ lbs. × 2″) $-$ (6 lbs. × 7″) + ($3\frac{3}{4}$ lbs. × 10″) = ($4\frac{1}{2} - 42 + 37\frac{1}{2}$) in.-lbs. = o.

Lastly, take a point through which one of the forces acts. Then by § 43 the moment of that force is nil. Taking the point *B*, the only forces producing rotation are the $2\frac{1}{4}$ lbs. and the 6 lbs.

The moments are ($2\frac{1}{4} \times 8 - 6 \times 3$) in. lbs. = $(18-18)$ in. lbs. = o.

46. From the foregoing example it will be seen that—

If a system of forces be in equilibrium, the algebraical sum of the moments of all the forces about any point is zero.

47. The converse of this is also true, so—

If the algebraical sum of the moments of all the forces in a system be zero, then the system is in equilibrium.

48. Further—

The moment of the resultant of any number of forces about any point is equal to the algebraical sum of the moments of all those forces about the same point.

For, taking Fig. 22, the force at *A* may be considered the equilibrant of the other two, and, if the sense be reversed, it will represent the resultant of the same *two, (§ 35).*

Take the moments about the centre.

The force at A now acts downwards, so the moment of this force is $2\frac{1}{4}$ lbs. $\times 4'' = +9$ in.-lbs.

The moments of the other two forces are $(15 - 6)$ in.-lbs. $= +9$ in.-lbs.

49. If, then, it be necessary to find the moments of a number of forces about a point, it is sufficient to find the moment of the resultant of those forces about that point.

50. The knowledge we have gained of these moments is of great assistance in determining forces.

Fig. 23 represents a beam resting on two walls, A and B, 12 ft. apart, and carrying a load of 6 tons 4 ft. from B.

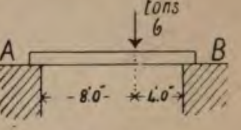


FIG. 23.

It is necessary to find what portion of the load each wall carries.

The reactions of $A + B = 6$ tons.

There are two unknown forces, so we will take the moments about the point B to eliminate the moment of that force (§ 43).

Let A's share of the load be called x tons.

Then 6 tons $\times 4' - x$ tons $\times 12' = 0$ (§ 46), therefore x tons $\times 12' = 6$ tons $\times 4'$, and x tons $= \dfrac{6 \text{ tons} \times 4'}{12'}$ $= 2$ tons $= A$'s share. But $A + B = 6$ tons; therefore B's portion is 4 tons.

51. The student will recognize x tons $= \dfrac{6 \text{ tons} \times 4 \text{ ft.}}{12 \text{ ft.}}$ as a proportion (§ 13), hence x may be found graphically.

In the above expression there are feet and tons, hence two different scales are necessary, the one to set

out the length of the beam and the position of the load, and the other by which to draw the magnitude of the load.

The former is an ordinary lineal scale, and the latter is known as the force scale.

Set out the beam to scale (say $\frac{1}{8}'' = 1'$), and mark the position of the load (Fig. 24).

To find A's load, set up at A the perpendicular $A\,D = 6$ tons by scale (say $\frac{1}{4}'' = 1$ ton).

Join $B\,D$, and erect the perpendicular $C\,E$ to meet it.

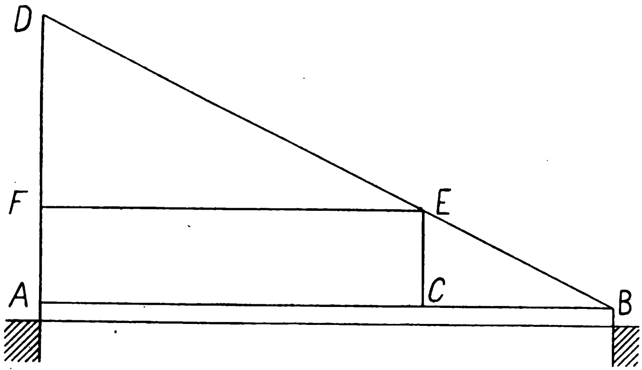


FIG. 24.

Then $C\,E = x$ (§ 13) $= A$'s load drawn to scale $= 2$ tons.

To find B's load, draw from E the line E F parallel to $A\,B$. Since $A\,F = C\,E = A$'s load, and $A\,D = 6$ tons, therefore $F\,D = B$'s load $= 4$ tons.

52. Fig. 25 represents a beam supporting two loads. Find the reactions of the supports.

Let A again $= x$ tons, and take the moments about B.

Then 4 tons $\times$ 8 ft. + 5 tons $\times$ 12 ft. $- x$ tons $\times$ 18 ft. $=$ o,

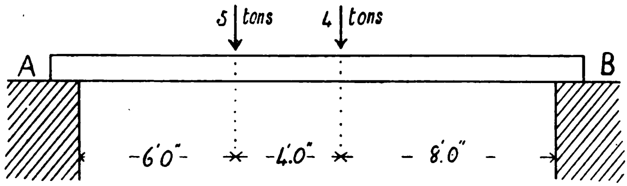


FIG. 25.

so x tons $\times$ 18 ft. $=$ (32 + 60) ft.-tons,

and x tons $= \dfrac{(32 + 60) \text{ ft.-tons}}{18 \text{ ft.}} = 5\frac{1}{9}$ tons $= A$'s load.

Therefore B's load $= 9$ tons $- 5\frac{1}{9}$ tons $= 3\frac{8}{9}$ tons.

To find these reactions, as shown in Fig. 24, would necessitate two figures and the answers added together. In Chapter V a better method will be shown for graphically finding the reactions when there is more than one load.

53. If the beam carries a uniformly distributed load over its whole length, then each support carries one-half the total load.

54. To ascertain this arithmetically or graphically the whole load must be considered as concentrated at its centre of gravity, which will be over the centre of the beam.

55. If the load be uniformly distributed over a portion of the length of the beam, the load must be treated as acting at its centre of gravity.

56. POINT OF APPLICATION OF THE RESULTANT OF PARALLEL FORCES.—It was pointed out (in § 31) that the resultant of a number of forces is the force which can be substituted for them, and, in the case of parallel forces, it is equal to their algebraical sum.

It is now necessary to find the point of application

of the resultant, that is, a point in the line along which the resultant would act to do the same work as the forces for which it is substituted.

Since the algebraical sum of the moments of all the forces about a point is equal to the moment of the resultant about the same point (§ 48), and the moment of the resultant about the point through which it acts is zero (§ 43), then the algebraical sum of the moments of all the other forces about that point is zero.

57. First Case. To find the point of application of the resultant of two forces when they act in opposite directions.

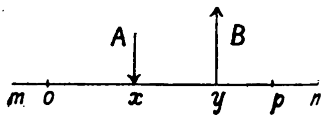


FIG. 26.

Let two forces, A and B, of which B is the greater, act in opposite directions.

Draw a line $m\ n$ perpendicular to their lines of action, and meeting them at x and y (Fig. 26).

It is now necessary to find a point in $m\ n$ such that the algebraical sum of the moments of A and B about that point will be zero.

An examination of the figure will show that the point cannot be between x and y because the two forces would cause rotation in the same direction about any point in $x\ y$.

Take any point o outside the smaller force.

If this be the point, then $A.o\ x = B.o\ y$.

But A is less than B, and $o\ x$ is less than $o\ y$, and the product of two smaller quantities cannot be equal to the product of two greater ones.

Hence, the required point cannot be outside the

smaller force. It must therefore be outside the greater force, and, if p be the point, will be such that $B.py = A.px$. By § 37 the resultant is equal to $B-A$.

Example.—If two forces equal to 9 lbs. and 4 lbs. act in opposite directions, find the resultant force and its point of application when the distance between the forces is 5 ft.

Adopt a lineal and a force scale.

Draw any line xy perpendicular to the lines of action of the forces (Fig. 27).

Let A be the point where the smaller force would meet it, and B the point of intersection of the greater, 5 ft. from it.

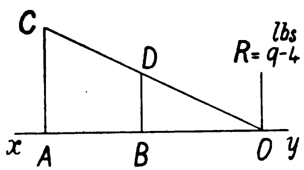


FIG. 27.

From A erect a perpendicular $AC = 9$ lbs., and from B, $BD = 4$ lbs.

Join CD and produce it to meet xy in O.

Then O is a point in the line of action of the resultant.

The resultant force is $(9-4)$ lbs. $=5$ lbs., and it acts in the same direction as the 9 lbs.

Proof.—The triangles CAO and DBO are similar.

Therefore $CA : AO :: DB : BO$

and $CA \times BO = DB \times AO$.

But $CA = 9$ lbs., and $DB = 5$ lbs.,

therefore 9 lbs. $\times BO = 5$ lbs. $\times AO$.

The distance of O from either A or B can be obtained by applying the lineal scale.

58. Second Case. To find the point of application of the resultant of two forces when they act in the same direction.

Let two forces, A and B, of which B is the greater, act in the same direction.

Draw a line $m\,n$ perpendicular to their lines of action, and meeting them at x and y (Fig. 28).

Suppose a point to be taken to the left of A.

The forces A and B would cause rotation in the same direction around this point, hence the algebraical sum of their moments cannot be zero.

The resultant, therefore, cannot be to the left of A.

Similarly it cannot act to the right of B.

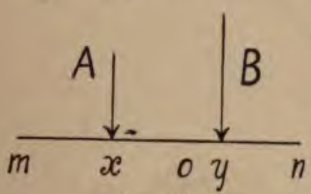


FIG. 28.

It must therefore act between A and B.

Suppose it acts through the point o.

Then $A . o\,x - B . o\,y = o$, and $A . o\,x = B . o\,y$.

But B was taken greater than A, therefore $o\,y$ must be less than $o\,x$, that is, the point o must be nearer the greater force.

59. Hence, if two forces act in the same direction, the line of action of the resultant is between them, and nearer the greater force, and by § 37 the resultant is equal to the sum of the two.

60. If the two forces be equal, the line of action of the resultant will be midway between them.

61. If the point of application of one force be joined to that of another like force, the resultant must pass through the line joining them.

62. *Example.*—Two parallel forces equal to 7 lbs. and 9 lbs. are 8 ft. apart, and act in the same direction.

Find the magnitude of the resultant and where it acts.

Adopt two scales—say, lineal scale $\frac{1}{4}'' = 1$ ft.
and force scale $\frac{1}{5}'' = 1$ lb.

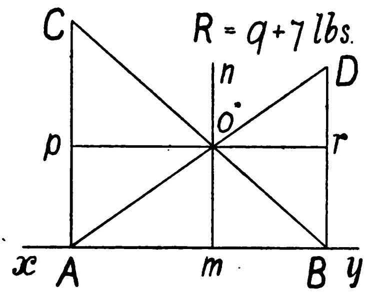


FIG. 29.

Draw any line $x\ y$ crossing their lines of action at right angles.

Let A (Fig. 29) be a point in the line of action of the smaller force, and at this point erect the perpendicular $A\ C$ equal to 9 lbs.

Let B be a point 8 ft. from it in the line of action of the larger force, and from B erect the perpendicular $B\ D$ equal to 7 lbs.

(Note the perpendiculars are drawn inversely to the magnitude of the forces.)

Join $A\ D$ and $B\ C$, then the point o where these lines intersect is a point in the line of action of the resultant.

Through o draw the perpendicular $m\ n$.

Then $m\ n$ represents the resultant, whose magnitude is equal to the sum of the forces 16 lbs., whose line of action is through o, and which acts in the same direction as the other two forces.

Proof.—Draw $p\ o\ r$ parallel to $x\ y$.

The triangles A o C and D o B are similar,

therefore $A\,C : o\,p :: B\,D : o\,r$
and $A\,C \times o\,r = B\,D \times o\,p$.
But $A\,C = 9$ lbs., and $B\,D = 7$ lbs.
Therefore 9 lbs. $\times\ o\,r = 7$ lbs. $\times\ o\,p$,
or 9 lbs. $\times\ o\,r - 7$ lbs. $\times\ o\,p = o$.

LEVERS.

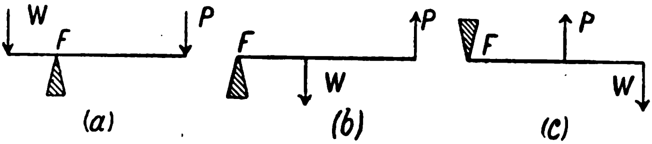


FIG. 30.

63. Fig. 30 represents the three orders of levers (a) being the first order, (b) the second, and (c) the third order. In each case W means the weight or resistance, P the power, and F the fulcrum.

The distance from the fulcrum (F) to the weight (W) is called the "weight arm," and the distance from the fulcrum to the power (P) is called the "power arm."

64. To solve problems on the lever arithmetically the moments of W and P about F are taken.

The moment of W about $F =$ the moment of P about F,

therefore $W \times$ the weight arm $= P \times$ the power arm,

$$\text{and} \quad W = \frac{P \times \text{power arm}}{\text{weight arm}};$$

$$\text{and} \quad P = \frac{W \times \text{weight arm}}{\text{power arm}};$$

$$\text{and} \quad \text{power arm} = \frac{\text{weight arm} \times W}{P};$$

$$\text{and} \quad \text{weight arm} = \frac{\text{power arm} \times P}{W}.$$

65. It will be noticed that the equations are similar to those used for graphically working proportions, therefore problems on the lever may be similarly solved.

Let $B\,C$ (Fig. 31) be a lever of the first order, with $A\,B$ as the weight arm, and $A\,C$ the power arm.

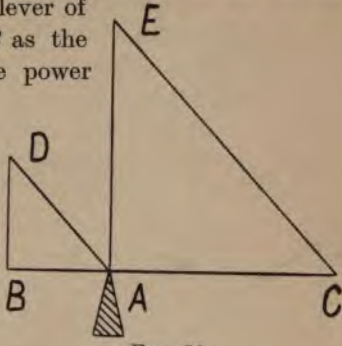


Fig. 31.

(*a*) To find the weight, draw the perpendicular $B\,D$, equal to the power, at the end of the weight arm, and join $A\,D$. From C draw $C\,E$ parallel to $A\,D$ and meeting the perpendicular $A\,E$ at E.

Then $A\,E$ is the required weight drawn to scale.

(*b*) To find the power, draw the perpendicular $A\,E$ equal to the weight at the end of the power arm, and join $C\,E$. From A draw $A\,D$ parallel to $C\,E$ until it cuts the perpendicular from B at D.

Then $B\,D =$ the power.

(*c*) To find the power arm, draw the perpendiculars $B\,D$ and $A\,E$ equal to the power and weight respectively. Join $D\,A$. From E draw the line $E\,C$ parallel to $D\,A$. The interception of the line $E\,C$ with the lever determines the length of the power arm.

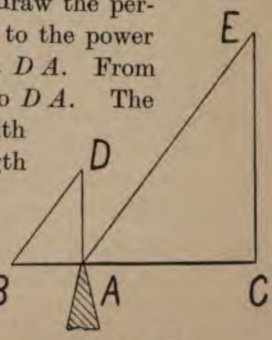


Fig. 32.

(*d*) In order to find the weight arm, the diagram is modified a little, as shown in Fig. 32.

The weight is set up from

C instead of from A, and the power from A instead of from B. The line $D\,B$ being drawn parallel to $A\,E$ determines the length of $A\,B$. The power or weight can also be found with this diagram.

Proofs for (*a*), (*b*), and (*c*)—

The triangles $A\,B\,D$ and $C\,A\,E$ (Fig. 31) are similar,

therefore $D\,B : A\,B :: A\,E : A\,C$,

and $D\,B \times A\,C = E\,A \times A\,B$:

i.e. $W \times$ weight arm $= P \times$ power arm.

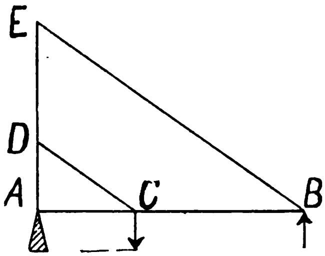


Fig. 33.

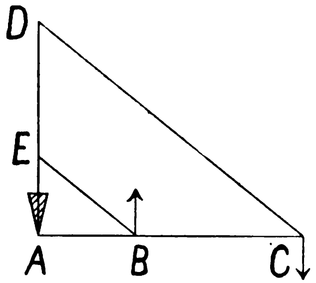


Fig. 34.

(*d*) can be similarly proved.

66. Second and Third Order of Levers.

Suppose $A\,B$ and $A\,C$ (Figs. 33 or 34) to represent the power arm and the weight arm respectively of a lever of the Second Order (or Third Order).

(*a*) To find the weight, draw the perpendicular $A\,D$ equal to the power. Join $C\,D$, and from B draw $B\,E$ parallel to $C\,D$ until it intercepts the perpendicular $A\,E$.

Then $A\,E =$ the weight.

(*b*) To find the power, draw the perpendicular $A\,E$ equal to the weight. Join $B\,E$, and from C draw $C\,D$ parallel to $B\,E$.

Then $A\,E =$ the power.

(*c*) To find the power arm, set up *A D* equal to the power, and *A E* equal to the weight. Join *C D* and draw *E B* parallel to *C D*. The point where *E B* intercepts the lever is the end of the power arm.

(*d*) To find the weight arm, set up *A D* and *A E* as before. Join *B E*. From *D* draw *D C* parallel to *B E*. The point *C* is the position of the weight, and *A C* is the weight arm.

67. The "weight" and "power" in the First Order of levers form a good illustration of "like parallel forces" (§ 58), the point of application of the resultant being at the fulcrum.

Since the lever is in equilibrium, the resultant must be balanced by an equal and opposite force. This second force is the reaction of the fulcrum, and is equal to the sum of the weight and power.

Similarly the second and third orders of levers illustrate "unlike parallel forces" (§ 57), the reaction of the fulcrum again being equal and opposite to the resultant of the two forces.

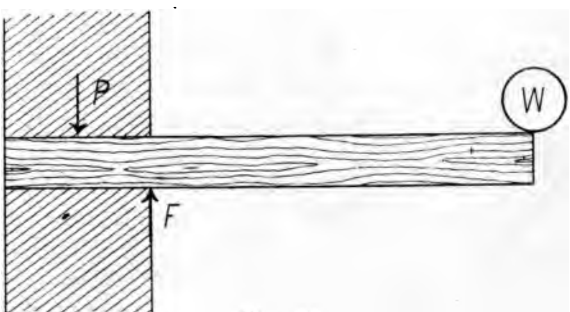


FIG. 35.

68. It will be seen by Fig. 35 that a cantilever is

a lever of the first order, the fulcrum (*F*) being the point on which the lever tends to turn. The power (*P*) is supplied by the weight of the wall built on the lever.

69. A beam supported at both ends is a lever of the second order.

Either end may be considered as the fulcrum, if the other be treated as the power.

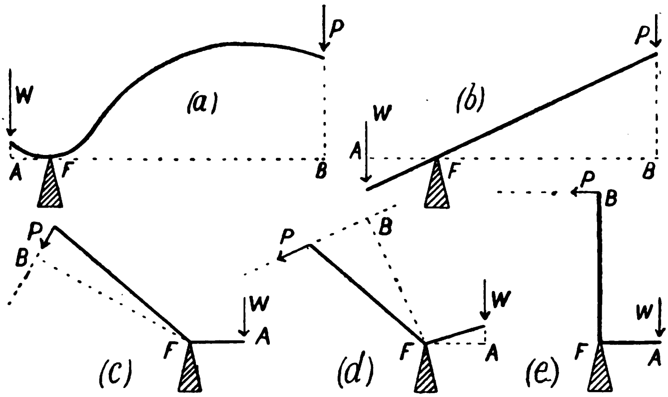


FIG. 36.

70. Levers need not necessarily be straight bars. They may be curved, as in Fig. 36 (*a*), cranked as in Fig. 36 (*c*), (*d*) and (*e*), or of any other form. The only essential point is that they should be rigid.

71. The "effective leverage" is the perpendicular distance from the fulcrum to the line of action of the force. This does not always correspond with the lengths of the weight and power arms, as will be seen by referring to Fig. 36 (*a*), (*b*), (*c*) and (*d*).

In each of these cases the weight and power arms must *be taken* as represented by *F A* and *F B* respectively.

72. A little consideration will show that the most economic way to utilize a power is by placing it at right angles to the power arm, because that is the way by which the greatest "effective leverage" can be obtained.

73. If either the power or the weight (or both) be not perpendicular to their respective arms, the solutions can be worked in very much the same way as previously shown. For, let *O F A* (Fig. 37) represent a lever with the weight acting perpendicularly at *A*, and the power in the direction shown at *O*. Then *F A*

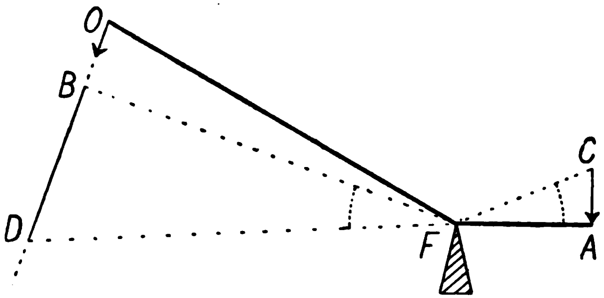


FIG. 37.

will represent the leverage of the weight, and *F B* the leverage of the power.

At *A* erect the perpendicular *A C* equal to the power, and join *F C*. Make the angle *B F D* equal to the angle *A F C*. Let the line *F D* intercept the direction of the power at *D*. Then *B D* will represent the weight.

To find the power, make *B D* equal to the weight and join *F D*. Make the angle *A F C* equal to the angle *B F D*, and let the line *F C* meet the perpendicular from *A* at *C*. Then *A C* will represent the power.

To work the above problem mathematically, $B\,F$ and $F\,A$ will still represent the leverages, therefore, taking the moments about F,

$$P \times F\,B = W \times F\,A.$$

The forces shown in Fig. 36 (*c*), (*d*) and (*e*) are not parallel. In Chapter IV a better method will be shown for dealing with these cases.

Examples to Chapter II.

1. If the force scale be $\frac{3}{4}'' = 100$ lbs., what does $A\,B$ represent ?

Ex. Ch. II.—Quest. 1.

2. A body weighs 46 lbs. To a scale of $\frac{1}{2}'' = 10$ lbs. draw a line showing the force exerted by it.

3. One force is equal to 12·5 lbs., and another, acting in the same straight line, is equal to 23 lbs.

Graphically show the resultant—

(*a*) if they act in the same direction.

(*b*) if they act in opposite directions.

4. A beam, 12 ft. long and weighing $1\frac{1}{4}$ cwts., supports a load of 4 cwts. at its centre, and another of 3·5 cwts. 4 ft. from one end.

(*a*) Draw a line showing the total load.

(*b*) What is the total reactions of the walls ?

(*c*) What is the direction of the reactions ?

5. A ladder leans against a smooth upright wall. What is the direction of the force exerted by the wall to support it ?

6. What is meant by *the moment of a force ?* How *is it* found ?

7. A cantilever 5 ft. long supports a load of 2 cwts. at its outer end.

What is the moment of the load—

(*a*) at the wall end ?

(*b*) at the centre ?

(*c*) at the outer end ?

8. A beam over a 15′.0″ span carries a certain concentrated load.

If the reactions of the supports due to this load be $4\frac{1}{8}$ tons and $1\frac{3}{8}$ tons respectively, what is the amount of the load, and where is it placed ?

9. A bar 4′.6″ long works on a pivot which is 1′.6″ from one end.

If a weight of 21 cwts. be placed at the end of the shorter section, what weight must be placed at the end of the longer section to balance it ? (Neglect the weight of the bar.)

10. Two walls 6′ apart support a beam on which is placed a load weighing 1200 lbs.

(*a*) If the load is placed 2·5 ft. from one end, what portion of the load does each wall support ?

(*b*) If the beam weighs 150 lbs., what is the total load on each wall ?

Chapter III

CENTRE OF GRAVITY—BOW'S NOTATION

74. Centre of Gravity.—We speak of the weight of a body. The weight is simply a downward force exerted by gravity. The body is made up of innumerable particles, on each of which gravity exerts a downward force. These forces, for all practical purposes, may be considered as parallel, and the weight of the body is the resultant of all these smaller forces.

If a solid body be freely supported in any position, the line of action of the resultant force will pass vertically through the body. If it be held from a different point, the force exerted on each particle, and the resultant of these forces, will again be vertical, and the second resultant will intersect the first at a certain point. In whatever position the body is held the resultant forces will cross each other at the same point.

This point is called the Centre of Gravity (c.g.) of the body, and we may assume that its whole weight is concentrated there.

75. The c.g. of a thin sheet can easily be found experimentally by suspending the sheet in any position and marking across it in line with the suspension string, as shown in Fig. 38 (*a*). Suspend it in another position, and mark as before (Fig. 38 (*b*)).

The intersection of these two lines will give the c.g. of the sheet.

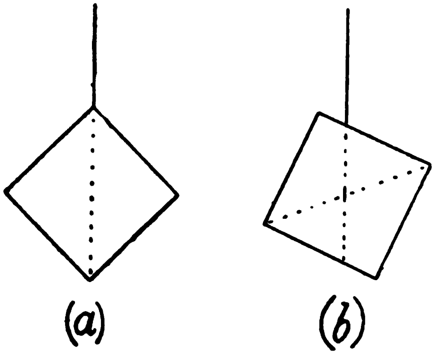


FIG. 38.

76. The c.g. of a thin sheet or lamina in the form of a parallelogram is given by the intersection of the diagonals (Fig. 39).

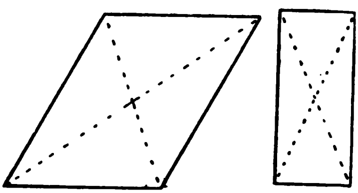


FIG. 39.

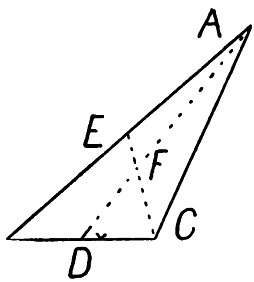


FIG. 40.

77. To find the c.g. of the triangular lamina *A B C* (Fig. 40), bisect the side *B C* in *D*, and join *A D*. Bisect another side as *A B* in *E*, and join *E C*.

The point *F*, where *E C* cuts *A D*, is the c.g. of the triangle.

F D is $\frac{1}{3}$ of *A D*, and *F E* is $\frac{1}{3}$ of *C E*, therefore we

may find the c.g. of a triangle by joining the middle point of any side to the opposite angle, and taking a point on this line $\frac{1}{3}$ of its length from the bisected line. The student may adopt either method.

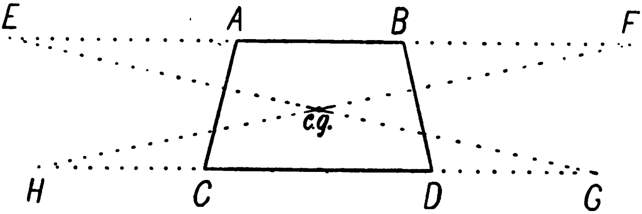


FIG. 41.

78. The c.g. of a trapezium or trapezoid. Let $A\ B\ C\ D$ (Fig. 41) be the trapezium. On each side of $A\ B$ mark off $A\ E$ and $B\ F$ equal to the base $C\ D$, and on each side of $C\ D$ mark off $C\ H$ and $D\ G$ equal to the top $A\ B$. Join $E\ G$ and $F\ H$. The intersection of these lines gives the c.g. of $A\ B\ C\ D$.

79. To find the c.g. of irregular rectilineal figures it is generally necessary to divide the figure into triangles or parallelograms.

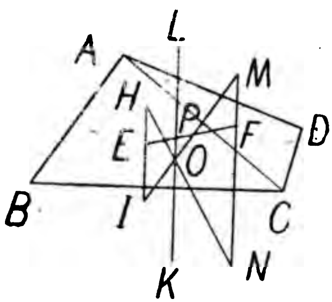


FIG. 42.

As an example, we will proceed to find the c.g. of the quadrilateral $A\ B\ C\ D$ (Fig. 42).

Divide the figure into two triangles by joining $A\ C$.

Find the c.g. of each as shown in § 77, and let these be at E and F.

These two triangles

are portions of a figure which is supposed to be of uniform density, therefore the weight of each is in proportion to its area. But the weight of each is a downward force acting at its c.g. (§ 74), hence we have two like parallel forces, and it is necessary to find the resultant force.

Through E, the c.g. of the larger triangle, draw the perpendicular $H\ I$ equal to the smaller force, and through F, the c.g. of the smaller triangle, draw the perpendicular $M\ N$ equal to the larger force. Join $H\ N$ and $M\ I$. Through O, where they intersect, draw the perpendicular $L\ K$.

Then $L\ K$ is the line of action of the resultant of the two forces at E and F, that is, of the two triangles. But the two triangles make up the figure $A\ B\ C\ D$, therefore it is the line of action of the resultant of the whole figure, hence the c.g. of the whole figure lies in $L\ K$.

But it is clear that the c.g. of the whole figure must lie in a line joining the c.g.s of its two portions, therefore the c.g. of the whole figure is at the point P, where the line $L\ K$ crosses the line $E\ F$.

80. To find the c.g. of a mass whose cross section is uniform in size and shape, it is sufficient to find the c.g. of a lamina of the same size and shape as the cross section.

Fig. 43 represents a wall of regular dimensions. If this wall be considered divided up into an indefinite number of thin vertical sections parallel with the end of the wall, then A (the intersection of the diagonals) gives the c.g. of the first lamina, and B the c.g. of the last.

The line $A\ B$ passes through the c.g. of each lamina,

and C, the middle point of $A\,B$, is the c.g. of the whole wall.

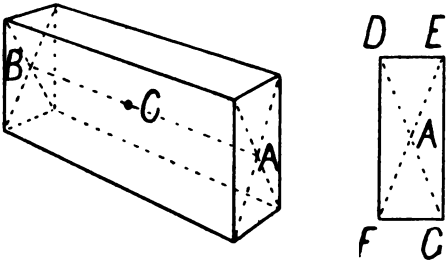


FIG. 43.

$D\,E\,F\,G$ is a cross section of the same wall, so it can be seen that the c.g. of the whole wall comes directly behind the point A, the c.g. of a lamina of cross section.

The student will now understand why P (Fig. 35) is placed at half the thickness of the wall, this being the centre of the pressure exerted by the wall.

81. The c.g. of a door may be found by drawing the diagonals.

Since the weight of a door acts vertically through its c.g., the leverage with which the door acts on its hinges is half the width of the door. Either hinge may be considered as the fulcrum, then the other becomes the power which maintains equilibrium.

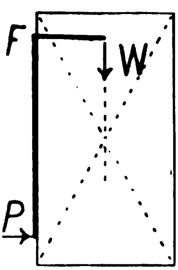


FIG. 44.

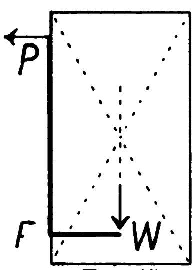


FIG. 45.

Thus a door is an example of a lever, the weight being

represented by the weight of the door, the weight arm being half the width of the door, the power being the reaction at one of the hinges, the power arm the distance between the two hinges, and the fulcrum the other hinge.

Reference to Figs. 44 and 45 will make this clear.

82. Bow's Notation.—Before proceeding any further, it may be advisable to explain the system of lettering diagrams as devised by R. H. Bow, C.E., F.R.S.E. This system has innumerable advantages, and will amply repay the student for the time spent in mastering it.

It will be adopted in all the succeeding exercises. It consists of lettering (or numbering) all the angles or spaces formed by the external forces, and when naming a force to do so clockwise.

Fig. 46 is given as an illustration.

Here there are three forces acting upwards, and two acting downwards, and, if the system be in equilibrium, the sum of the three forces is equal to the sum of the two.

There are five forces, consequently five spaces. Place a letter in each space as A, B, C, D, and E. Other letters or numbers would do, and they may be placed in any order, but it is well to be systematic

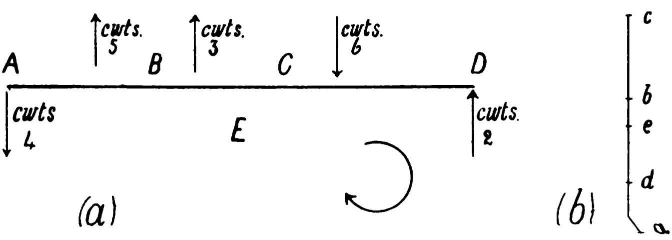


Fig. 46.

and adopt a uniform practice. There is a force dividing the spaces A and B, so this force will be named by those two letters, but as in clockwise order A would come before B, the force is named $A\ B$, not $B\ A$. Similarly the other forces are $B\ C$, $C\ D$, $D\ E$, and $A\ E$.

83. It will be necessary to draw lines representing the magnitude and direction of those forces, which lines will have the same names as the above, but small letters will be used instead of capitals.

84. Now, if a line as X ———— Y represents a force, the force must be considered as acting from X to Y or from Y to X, that is, X or Y must be first in its course of action.

In Bow's notation the letter which is placed first in the course of action of a force is the one which comes first in the clockwise notation.

Draw a line representing the force $A\ B$ (Fig. 46).

Since A is the first letter in the clockwise order, and the force acts upwards, a must be placed at the bottom. The next force is $B\ C$, and this acts upwards, so the b of the first force becomes the first point in the line of action of the second force, which is again drawn upwards. Similarly the c of the second force becomes the first point of the third force $C\ D$, but this force acts downwards, so $c\ d$ must be measured off downwards. $D\ E$ acts upwards, hence $d\ e$ must be measured upwards. $E\ A$ acts downwards, and $e\ a$ is measured in that direction.

(It should be noted that this is simply an application of addition and subtraction as shown in § 9.)

As this last point corresponds with the first, the answer,

or resultant, is zero. If the last point had not fallen on the first, there would have been a resultant force acting upwards or downwards according as the last point would have been above or below a.

85. The diagram showing the beam (or any other structure) and the position of its loads is called the "frame diagram," and the diagram representing the forces drawn to scale is called the "force diagram."

Fig. 46 (a) is the frame diagram, and Fig. 46 (b) is the force diagram.

86. This method is extremely useful in finding the resultant of any number of forces. The forces, as shown on the frame diagram, should be named in clockwise order, then the first and last letters will name the resultant and give its direction as shown on the force diagram.

Referring to Fig. 46, let it be required to find the resultant of the three forces shown on the top of the beam. These forces are $A\,B$, $B\,C$, and $C\,D$. A is the first letter, and D the last of this series, so $a\,d$ on the force diagram represents the magnitude and direction of the resultant force. By measuring $a\,d$ it is found equal to 2 cwts., and as $a\,d$ also gives the direction, the force acts from a to d, that is, in an upward direction.

Again, suppose the resultant of the two forces on the right is required. These are $C\,D$ and $D\,E$. The first and last letter are C and E, so $c\,e$ on the force diagram fully represents the resultant of these forces, and is equal to 4 cwts., acting in a downward direction.

87. As in the case of the known forces, the letters have to be placed with due regard to the direction in which the force is acting, so will the letters indicate the direction of the unknown ones.

Suppose it had been required to find the direction of the force on the left of Fig. 46 (*a*). This force is known as *E A*, and on referring to the force diagram we find that to proceed from *e* to *a* we go downwards, hence the force *E A* acts in that direction.

88. If the structure on which the forces act be an open framed one, in addition to the spaces between the external forces being lettered, a letter is placed in every space of the frame.

As an example see Fig. 47.

The external forces are the load of 3 tons and the two reactions of the supports. The force exerted by

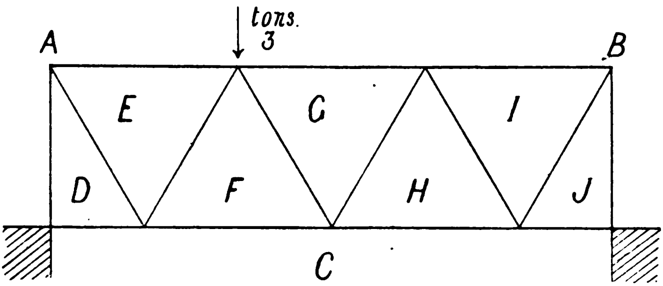


FIG. 47.

the left hand support would be known as *C A*, the 3 tons load as *A B*, and the force exerted by the right hand support as *B C*.

The spaces in the frame are now lettered as *D*, *E*, *F*, *G*, *H*, *I* and *J*.

89. An examination of the figure will show that there is a letter on each side of every bar, and these letters will name the bar, but which letter comes first in considering the forces will depend on which end of *the bar* is under consideration. Thus, take the bar

dividing the spaces F and C. The bars meeting at the left of this are named, according to the clockwise order, $C\,D$, $D\,E$, $E\,F$ and $F\,C$, and at the other end they are $F\,G$, $G\,H$, $H\,C$, and $C\,F$. Hence, when dealing with the one end the bar is named $F\,C$, and when dealing with the other it becomes $C\,F$.

90. As this part of the work is devoted to Bow's notation, there are two other things which it may be advantageous to point out, but which will not be thoroughly understood until the student is dealing with the effects of loads upon framed structures (Chap. VII.).

The first of these is——— Every bar surrounding a space in the frame diagram meets at the same point in the stress diagram, and this point is named by the letter in the space of the frame diagram.

The second is——— The external forces and bars meeting at a point in the frame diagram will form the sides of a polygon in the stress diagram.

91. Load.—By a load on a structure is meant the sum of all the forces acting upon it, together with the weight of the structure itself.

92. Stress—tension and compression.—If a force acts on a body, it produces from that body an equal and opposite resisting force.

This resistance is known as stress.

If a weight be suspended by a string, the string exerts an upward force equal to the downward pull of the weight; and, if a prop or strut supports a load, it pushes against it with a force equal to that of the load.

The force exerted by the string in resisting elongation is called its tensile stress or tension, and the resistance to crushing set up in the strut is known as compressive stress or compression.

But we know that the string in itself could not support a weight without being attached to some support to which the string transmits the force. The string exerts a downward pull at the support, as well as an upward pull at the weight. Since each end of the string exerts a force equal to the weight, it might be supposed that the tension in the string is twice the force exerted by the weight, but it is not so.

93. The student can easily satisfy himself that the tension in the string is only equal to the force at one end if he will fit up an apparatus as shown in Fig. 48.

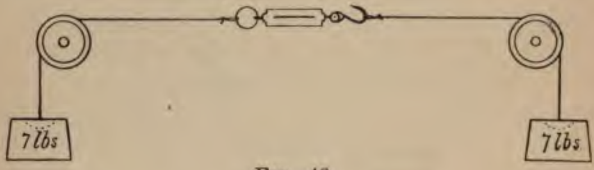


Fig. 48.

This consists of two equal weights, two pulleys, and a spring-balance attached to the two weights.

Although there is a force acting at each end, the balance will show that the tension is only equal to one of them.

Similarly with the strut, the load and the support each exert a force against it at opposite ends, but the stress set up is only equal to one of them.

When a bar is in tension each end exerts a force inwards, and these two forces are equal; and when a bar is in compression the two ends exert outward forces which are equal to one another.

By marking the senses at each end of a bar, a glance will show the kind of stress in that bar.

94. *Since a com*pression bar exerts an outward force

at each end, the arrows will point outwards, thus :—
⟵ ⟶; and since a tension bar exerts an inward pull at each end it is marked thus : ⟶ ⟵.

95. STRAIN.—The forces which produce tension or compression in a bar also cause an alteration in its form. This change of form may be so slight that, upon the removal of the forces, the bar will regain its original shape, or it may be such that the bar is permanently injured.

In either case this change of form is known as strain.

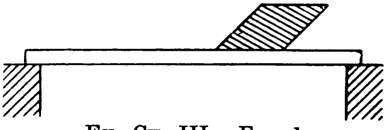
96. When expressing the amount of stress in a bar, the sign + (plus) is often prefixed for compression bars, and the sign − (minus) for tension bars, instead of indicating it by means of arrows.

Another method of indicating the kind of stress is to draw thick or double lines for compression bars and thin ones for tension bars.

EXAMPLES TO CHAPTER III.

1. Find the c.g. of a wall 6 ft. high, 3′ 6″ broad at the base, and 2′ at the top, one face being vertical.

2. Fig. 1 shows a beam supporting a body which weighs 225 lbs.

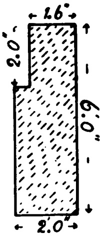


EX. CH. III.—FIG. 1.

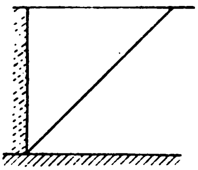
Draw a line indicating the position and direction of the force exerted by the body. Scale 1″=100 lbs.

3. Two loads, 3 tons and 4 tons, are placed 5 ft. apart on a beam. Where is the centre of pressure?

4. Draw a vertical line which will pass through the c.g. of the wall shown in Fig. 2.



Ex. Ch. III.—Fig. 2.



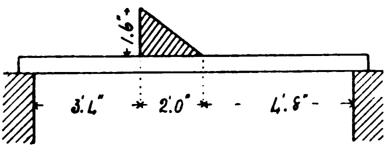
Ex. Ch. III.—Fig. 3.

If the wall shown weighs 135 lbs. per c. ft., what is its weight per foot run ?

5. Find the c.g. of the triangle Fig. 3.

6. Fig. 4 shows a triangular prism lying on a beam.

If the prism weighs 1,000 lbs., what are the reactions of each support due to it ?

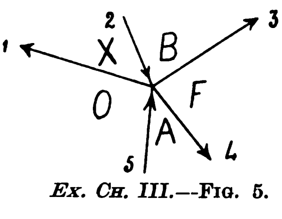


Ex. Ch. III.—Fig. 4.

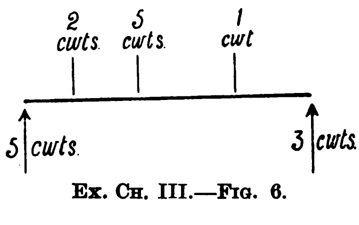
7. In Fig. 5 the directions of a number of forces acting at a point are given.

Name them according to Bow's Notation.

8. Fig. 6 represents five parallel forces in equilibrium.



Ex. Ch. III.—Fig. 5.

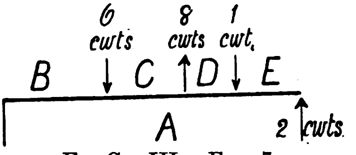


Ex. Ch. III.—Fig. 6.

Draw the force diagram. Scale 1″=4 cwts.

9. Five parallel forces in equilibrium are shown in Fig. 7.

Give the magnitude and direction of the force *A B*.



Ex. Ch. III.—Fig. 7.

10. A bar 5 ft. long is secured by a pivot at one end, while a 14 lb. weight is suspended at the other.

(*a*) Neglecting the weight of the lever, what power is required 2 ft. from the pivot to support it ?

(*b*) What are the magnitude and direction of the force exerted by the pivot ?

CHAPTER IV

PARALLELOGRAM, TRIANGLE, AND POLYGON OF FORCES, AND RETAINING WALLS

97. Up to the present only forces whose lines of action are parallel have been dealt with. It now becomes necessary to examine other forces.

The student should again take up his spring balances and arrange them as in Fig. 18. He may dispense with the pulley, and must remember that the balances are only used to register the force exerted by the string attached to each.

Now that the two strings are exerting a force parallel and opposite to that exerted by the weight, their sum is equal to the downward force. With the same weight attached, he should increase the distance between the points of suspension (Fig. 49). A glance at the balances may now cause him no little surprise. He should try them in three or four positions, each time increasing the distance between the points of support, and noting the results.

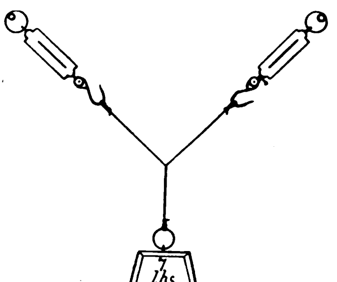


FIG. 49.

His observations may be summarized as follows :—

(*a*) When the supporting strings are no longer parallel to the line of action of the force exerted by the weight, the sum of the forces exerted by them exceeds that exerted by the weight. (*b*) The further they are from being parallel (that is, the greater the angle between them) the greater is the force they have to exert to support the weight.

98. Parallelogram of Forces.—Selecting one of these positions, and adopting a convenient scale, as $4'' = 1$ lb., a line should be marked behind, and parallel to, each supporting string, and the tension measured on each as indicated by the balance.

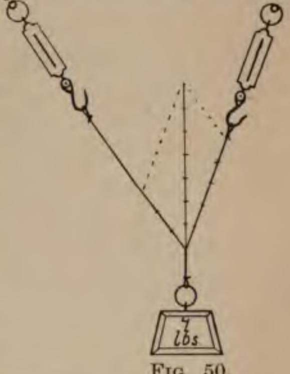


Fig. 50.

Complete the parallelogram, and draw the diagonal as shown in Fig. 50.

Measure the diagonal to the same scale.

Two things will now be noticed:—First, the diagonal measured to scale will give the same force as that exerted by the weight. Second, the diagonal will be in line with the string supporting the weight.

This should be verified by trying it in each of the former positions.

To change the direction of the pull of the weights, three pulleys and three weights should be fitted up as shown in Fig. 51.

It will be seen that similar results are obtained.

Further, any two of the forces can be utilized to find the third, as indicated by the dotted lines.

Let us examine these results further.

The force exerted by the weight keeps the other two forces in position, so it is the equilibrant of them (§ 33). The two strings *d a* and *d c* support the 7 lb. weight, and keep it in equilibrium, but a force which could be substituted for these two forces is their resultant, and to support the weight in that position it is evident that a force is required which is equal to that exerted

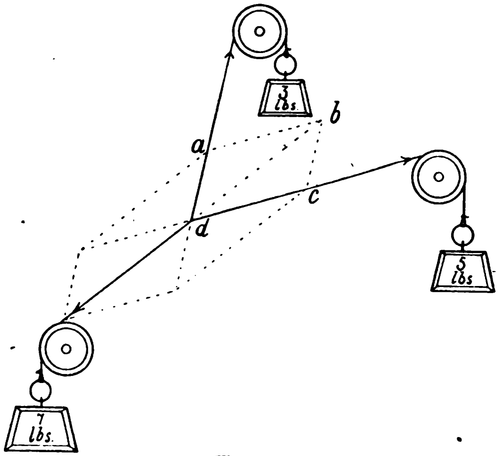


FIG. 51.

by the weight (or equilibrant), and which acts in the opposite direction and in the same straight line. But the diagonal of the above parallelogram measured to scale, gives a force equal to the equilibrant, and is in the same straight line, so if an arrow be placed on it indicating that it acts in the opposite direction to the equilibrant, it will represent the resultant of the other two forces.

99. Hence, if the magnitude and direction of two

forces be known, by completing the parallelogram and drawing the diagonal the magnitude and direction of the resultant force is obtained.

100. It is evident that the resultant of any two forces (not parallel) must pass through the point of intersection of the lines of action of the two forces.

101. If three non-parallel forces maintain equilibrium, the lines of direction of these forces, if produced, will meet at the same point. Any two of the forces can be replaced by a resultant, and, since the third force balanced these two, it will balance their resultant, and this it can only do by acting at the same point.

102.—TRIANGLE OF FORCES.—On further examining the parallelogram $a\ b\ c\ d$ (Fig. 51), it is seen to be made up of two equal triangles.

The triangle $a\ b\ d$ has the side $d\ a$ parallel and equal to the 3 lb. force, the side $a\ b$ parallel and equal to the 5 lb. force, and the side $b\ d$ parallel and equal to the 7 lb. force.

If $b\ d$ be considered as representing the equilibrant, then it will represent a force acting from b to d, and the three sides proceeding from d to a, a to b, and b to d, will give the sense of the three forces.

103. Hence, if three forces be in equilibrium, it is possible to draw a triangle with sides parallel to the line of action of each force, and representing them in magnitude each to each, and whose sides, taken in order round the triangle, will give the sense of each force.

If, therefore, the sense of one of the forces be known, the sense of the others is known.

104. The converse is equally true :—

If it be possible to form a triangle with sides parallel

to the lines of action of the forces and equal to them in magnitude, and whose sides represent the sense of each taken in order round the triangle, then the three forces are in equilibrium.

105. Each of these three forces must be the equilibrant of the other two, hence if the sense of one be reversed, then that force becomes the resultant of the others.

106. If, on examining a triangle of forces, it is found that the sense of one force is opposite to the others, then the force represented by that line is the resultant of the others.

107. If three forces (not parallel) maintain equilibrium, the sum of any two must be greater than the third.

Since the three are in equilibrium, it must be possible to form a triangle with sides parallel to and proportional to the forces, but unless any two are greater than the third this is impossible.

108. If three forces, of which the two smaller are equal to the greater, maintain equilibrium, then they are all parallel, and the two smaller act in the opposite direction to the greater.

109. Since, when three non-parallel forces are in equilibrium, it is possible to form a triangle with sides equal and parallel to the forces represented by them, and it is impossible to make any triangle with two parallel sides, there cannot be three such forces, two of which are parallel, in equilibrium.

110. If, then, in any structure there be three bars (or two bars and an external force) meeting at a point, and any two of them be parallel, the forces exerted by *the two* parallel ones are equal and opposite, and the

third bar exerts no force. (N.B.—This is not true if there be more than three bars or more than three bars and forces together.)

To illustrate this, three portions of different girders are shown (Fig. 52).

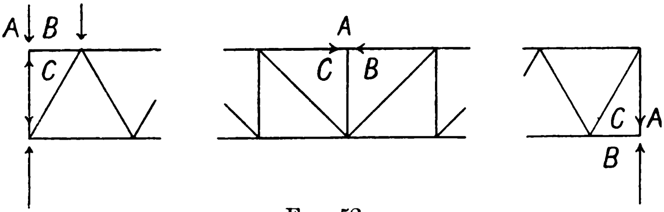


FIG. 52.

In each of the above cases the force exerted by $A\,B$ acts directly on the end of the bar $C\,A$, and produces from it an equal and opposite force. If there were either a pull or a thrust in $B\,C$, it is evident that equilibrium would not be maintained. But we know the joint is in equilibrium, hence there is neither tension nor compression in the bar $B\,C$, i.e. the force exerted by $B\,C = 0$.

111. If the magnitude of two forces maintaining equilibrium with a third force whose magnitude and direction is known, be given, then their directions can be ascertained.

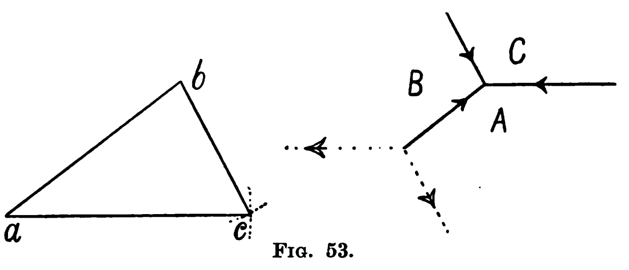


FIG. 53.

Let $A\ B$ (Fig. 53) be the known force. Draw $a\ b$ parallel and equal to this force. With a as centre, describe an arc with a radius equal to the line representing one of the other forces, and with b as centre and a radius equal to the line representing the remaining force describe an arc cutting the first at c. Join $c\ b$ and $c\ a$.

Their directions are given by $b\ c$ and $c\ a$, and a reference to Fig. 53 will show they can be transferred to either end of $A\ B$.

112. If three forces whose directions are given, act at a point in equilibrium, and the magnitude of one be known, then the magnitude of the others can be found.

Fig. 54 shows a wall and the foot of a roof truss. Suppose the reaction of the wall to be 30 cwts., then this is an upward force resisting the action of the rafter and the tiebeam.

Letter the spaces as shown, and draw $a\ b$ parallel to $A\ B$ and equal to 30 cwts. From b draw $b\ c$ parallel to $B\ C$, and from a draw a line parallel to $C\ A$. Then

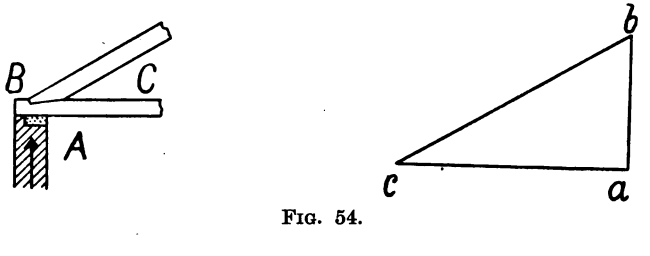


FIG. 54.

$b\ c$ and $c\ a$ give the magnitude and directions of the forces exerted by $B\ C$ and $C\ A$. $B\ C$ acts towards the joint, and $C\ A$ from it.

113. Two or more forces which have a resultant

force are called the components of that force.

The two forces *A* and *B* (Fig. 55) have a resultant force *R*. *R* is then the force which could be substituted for them (§ 31). It is equally correct to say that the forces *A* and *B* could be substituted for the force *R*.

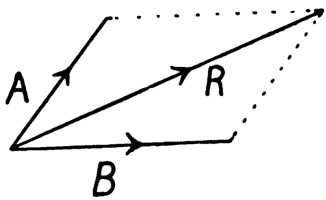


FIG. 55.

A and *B* are the components of *R*.

If the direction of the force *R* were reversed it would become the equilibrant of the forces *A* and *B* (§ 33), then the three forces would be in equilibrium. But in § 112 it was shown that if a force be known, the magnitude of two others producing equilibrium and acting along given directions could be found. Hence, if *R* were considered as acting in the opposite direction, the magnitude of the forces *A* and *B* could be determined.

Fig. 56 shows the foot of the rafter of a couple roof along which a force equal to $2\frac{1}{2}$ cwts. is acting. It is necessary to find the vertical and horizontal components.

If we consider the action of this force reversed, then it will act away from the joint. Draw *a b* to represent the $2\frac{1}{2}$ cwts. acting in that direction. From *b* draw a vertical line, and from *a* a horizontal one intersecting it at *c*.

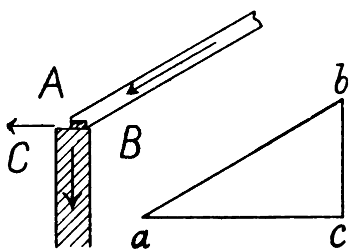


FIG. 56.

Then $b\,c$ and $c\,a$ will represent the two components in direction and magnitude.

(It should be noticed that the rafter $A\,B$ causes a horizontal thrust equal to $c\,a$, which tends to overturn the wall, and a vertical thrust equal to $b\,c$. These have to be resisted by the wall.)

114. If a body A (Fig. 57) be placed on a smooth inclined plane, it slides in the direction shown by the arrow. This sliding must be caused by some force acting in that direction. One of the forces acting on it must be its own weight, but this acts vertically, and could not of itself produce motion down the plane, so there must be another force acting on it. The other force is " the reaction of the plane," which always acts at right angles to the plane. The force which causes the body to move along the plane is the resultant of the force caused by the weight of the body and the reaction of the plane.

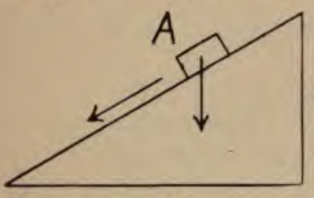


FIG. 57.

But the force acting along the plane, and the reaction of the plane, are two forces produced by the vertical force exerted by the weight of the body, hence they are components of that force.

The magnitude of this vertical force is known and the direction of the two component forces, so it is possible to find their magnitude (§ 113).

If it were necessary to keep the body from sliding, a force equal and opposite to the one acting along the plane would do it.

115. It is clear that a force applied horizontally, as

shown in Fig. 58, would also keep the body in equilibrium, hence the body must have a horizontal thrust equal to that necessary to keep it in position when applied in that direction. By resolving the vertical force exerted by the body into a force at right angles to the plane, and a horizontal one, the horizontal thrust of the body is obtained.

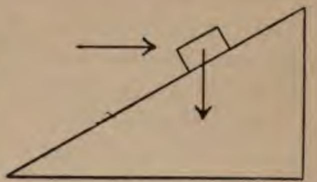


Fig. 58.

116. Since we know the weight of the body acts vertically, and the plane exerts a force at right angles to its surface, being given the weight of the body, and the inclination of the plane, we can find either the force the body exerts parallel to the plane, or the force it exerts horizontally.

117. Fig. 59 shows a cantilever supported by a strut and loaded with 2 cwts. Find the kind and amount of stress set up in each member.

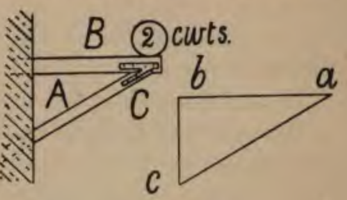


Fig. 59.

Letter the spaces on the frame diagram, and draw *b c* equal to 2 cwts. From *c* draw a line parallel to *C A*, and from *b* draw one parallel to *A B*. Let them meet at *a*.

Then *c a* and *a b* will represent the stresses.

Since the force represented by *b c* acts downwards and the sense must be in the same direction taken round the triangle, therefore *c* to *a* gives the direction of the force exerted by *C A*, and a to b gives the direc-

tion of the force exerted by *A B*. *c a* and *a b* measured to the same scale as that by which *b c* was drawn will give the magnitude of the forces exerted by *C A* and *A B* respectively.

Since *C A* acts outwards towards the joint, and *A B* inwards from it, the former is in compression and the latter in tension (§ 92).

118. Fig. 60 shows a loaded cantilever supported by a wrought iron rod.

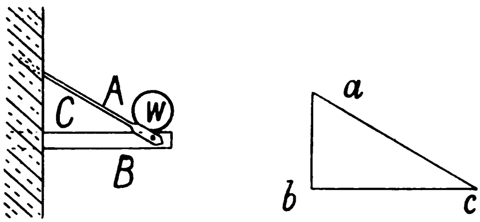


FIG. 60.

The construction of the force diagram needs no further explanation.

An examination of the force diagram will show that in this case the beam is in compression and the rod in tension.

119. The "triangle of forces" is most useful in the solution of levers when the forces acting on them are not parallel.

Let *A F B* (Fig. 61) be a lever with the "power" and "weight" acting as shown.

In order to maintain equilibrium there must be another force acting, and this is the "reaction of the fulcrum." There are then three "non-parallel" forces *maintaining* equilibrium, therefore the lines of direction

of these three forces must meet at the same point (§ 101).

Let the lines of direction of P and W meet at O, then

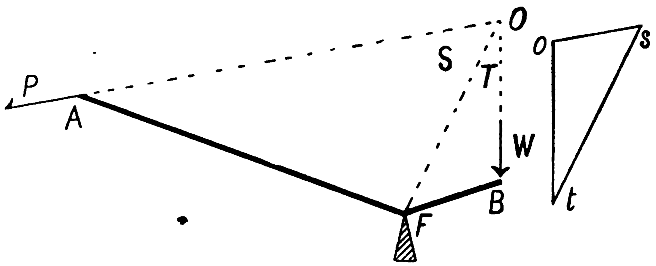


FIG. 61.

the line indicating the direction of the reaction of the fulcrum must pass through O. Since the reaction acts at the fulcrum, it must also pass through F, therefore the line $F\,O$ gives the direction of the reaction of the fulcrum.

At O there are now shown the directions of three forces in equilibrium, and, if one be known, the others can be determined (§ 112).

Suppose the weight (W) to be known.

Letter the spaces, and draw $o\,t$ parallel, and equal to, the weight. Complete the triangle of forces by drawing $o\,s$ parallel to $O\,S$, and $t\,s$ parallel to $T\,S$.

$t\,s$ completely represents the reaction of the fulcrum, and $s\,o$ completely represents the power.

120. Again, let Fig. 62 represent a door whose hinges are at A and B, and let it be required to find the horizontal reaction of the hinge A, and the total reaction of the hinge B.

Since it is the horizontal reaction of A that is re-

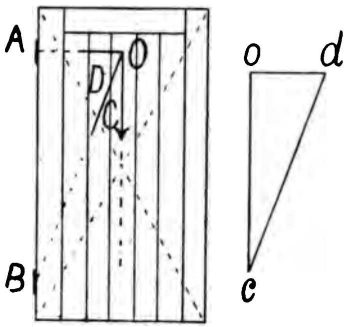


FIG. 62.

quired, its direction must intercept that of the force exerted by the door at *O*. Join *B O*.

Then *B O* gives the direction of the total reaction of the hinge at *B*.

At *O* the direction of three forces in equilibrium is given, and, since one of them, the weight of the door, is known, by applying the triangle of forces the others can be found.

121. The rafters of lean-to or pent roofs are often found fixed as shown in Fig. 63.

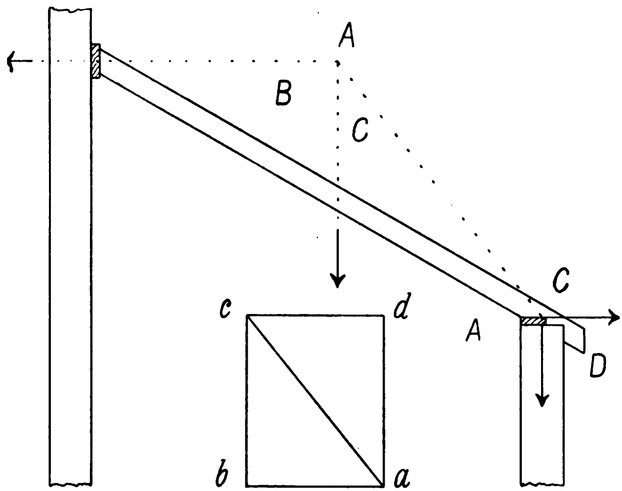


FIG. 63.

On examining the forces acting on this, it will be seen that the reaction of the one wall is in a horizontal direction, and this intercepts the line of action of the load on the roof at A. The third force is the reaction of the lower wall, and its direction must pass through the point of intersection of the other two forces (§ 101).

Its direction is therefore given by the line $A\,C$. Resolving $C\,B$ parallel to $B\,A$ and $A\,C$ the triangle $c\,b\,a$ is formed. $c\,a$ now gives the magnitude and direction of the thrust of the rafter, and, by finding the horizontal and vertical components of this thrust, it will be seen that the lower wall has to support the whole weight of the roof as well as resist a horizontal thrust, whose magnitude is given by $c\,d$.

By forming the rafter as shown in Fig. 64, the roof is supported by two parallel forces. Each wall then gets one-half the weight of the roof, and there is no horizontal thrust.

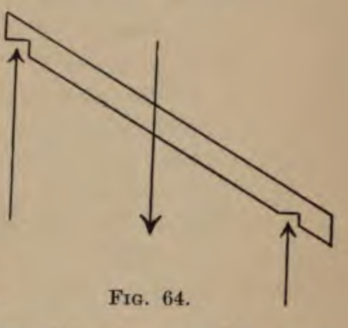


FIG. 64.

122. RETAINING WALLS.—Walls built to sustain water or earth are called retaining walls, and it is now intended to apply the knowledge gained in the preceding pages to ascertain whether any proposed retaining wall is sufficiently strong for its purpose.

Before this can be done, we must ascertain the forces at work.

It is clear that the wall is put to resist the thrust of

the water or earth behind it. We will first examine this resistance.

It was shown in Chapter III that the weight of a body can be considered as concentrated at its centre of gravity, so the force (or resistance) exerted by the retaining wall is its weight acting vertically through its c.g.

By taking a part of the wall 1 ft. in length, and the area of the cross section, we have the number of cubic feet in the part of the wall under consideration. Knowing the weight of 1 cub. ft. of the particular walling (say 1 cwt. for brickwork, and 140 lbs. for masonry), we can now ascertain the weight or vertical force exerted by the wall, and, since it acts through its c.g., we know its line of action.

123. Next, we will inquire into the force exerted by water on a retaining wall or dam.

Hydrostatics teaches us that water always exerts a pressure at right angles to the sides of the vessel containing it or the containing surfaces, and that the pressure at any point is in proportion to the vertical distance of this point below the surface of the water.

124. Since the pressure at the bottom of a retaining wall depends on the vertical height of the surface of the water above this point, a line equal to the depth of the water will represent the magnitude of the pressure at this point. But the pressure is at right angles to the surface of the wall, so the line representing the magnitude of the pressure must be drawn in that direction.

In Figs. 65 and 66, from b, the bottom of the wall, draw $b\,c$ perpendicular to $a\,b$ and equal to the vertical depth of the water; $b\,c$ now represents the magnitude

and direction of the pressure of the water at this point, where of course the pressure is greatest. If other points be taken on the wall, the pressure at these will be less as the vertical height to the surface decreases, until the top of the water is reached, where the pressure is *nil*.

Hence, if $a\,c$ be joined, the triangle $a\,b\,c$ will graphically represent the total pressure on a section of the wall. The ordinates are drawn showing the relative amount of pressure at different points.

125. The magnitude of this pressure must now be obtained.

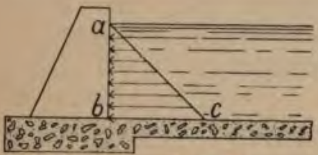


FIG. 65.

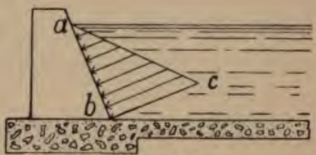


FIG. 66.

The triangle $a\,b\,c$ represents the section of a volume of water whose height is $b\,c$ and whose base is $a\,b$, and, if the volume pressing on 1 ft. of the length of the wall be taken, its cubical contents is $\dfrac{ab \times bc}{2}$ cubic feet.

But 1 cub. ft. of water weighs 62·5 lbs., therefore the total pressure exerted on 1 ft. of the length of the wall is $\dfrac{ab \times bc}{2} \times 62{\cdot}5$ lbs.

126. Having found the magnitude of the pressure, its direction and point of application must now be considered. The weight of the triangular volume of water represented by $a\,b\,c$ must be treated as if concentrated at its c.g., and it presses at right angles to

the inner surface of the wall, therefore a line through its c.g. perpendicular to this surface will give the direction of this pressure, and its point of application is where this line meets the wall.

The point of application is always $\frac{1}{3}$ of *a b* measured from *b*.

127. It is intended to build a stone wall 6 ft. high to dam a stream of water to a depth of 4 ft., the width at the base to be 3 ft., the top, 2 ft. 6 in., and the inner surface is vertical.

Find whether the wall is sufficiently strong.

Set out the wall and depth of water to some convenient scale (Fig. 67). From the base *b* mark off *b c* perpendicular to *a b* and equal to 4 ft. Join *a c*. The triangle *a b c* represents the pressure on the wall (§125).

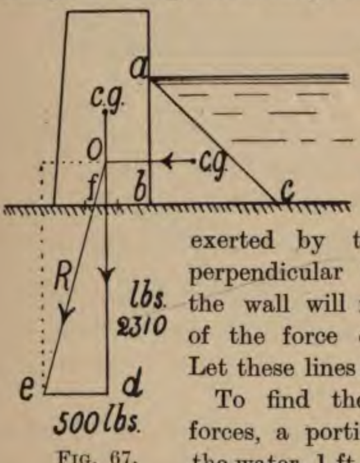


FIG. 67.

Find the c.g. of *a b c* and of the wall as shown in Chapter III.

A vertical line from the c.g. of the wall will represent the direction of the force exerted by the wall, and a line perpendicular to the inner face of the wall will represent the direction of the force exerted by the water. Let these lines intersect at *o*.

To find the magnitude of these forces, a portion of the wall and of the water, 1 ft. each in length, is taken,

then the wall weighs $\dfrac{2'\,6'' + 3'}{2} \times 6' \times 140 \text{ lbs.} = 2310 \text{ lbs.},$

and the water weighs $\dfrac{4' \times 4'}{2} \times 62{\cdot}5 \text{ lbs.} = 500 \text{ lbs.}$

These represent the magnitude of the forces acting in the directions shown.

From o scale off $o\,d = 2310$ lbs., and from d draw $d\,e = 500$ lbs. Join $o\,e$; then $o\,e$ represents the magnitude and direction of the resultant force, and $o\,e$ cuts the base of the wall at f.

128. To fulfil all the usual conditions necessary for the stability of a retaining wall for water, the resultant force must not intersect the base outside the middle third, but this rule is not universal in its application.

An examination of Fig. 67 will show that the point f is within the middle third, hence the proposed wall will be strong enough.

129. A retaining wall (brickwork) 7 ft. high has a batter of 1 in 8 on the outer surface. The base is 4 ft. and the top 1 ft. thick.

Ascertain whether it is safe to allow the water to rise to a depth of 6 ft.

Set out the wall to scale, and indicate the water line as before (Fig. 68).

The construction is similar to that of the last exercise.

The only point to be noted is that $b\,c$ and the centre of pressure of the water still remain perpendicular to $a\,b$.

The length of $a\,b$ is obtained by scaling it on the drawing.

The weight of the wall and the water is obtained as shown in the previous exercise.

It will be seen that the resultant falls outside the middle third, hence the wall is probably not strong enough (§ 128).

Note.—The question of stability depends partly upon the crushing force and the strength of material at the

outer edge, and cases may occur where perfect stability exists although the resultant may pass beyond the middle third.

To obtain a wall strong enough the thickness should be slightly increased, and the above test again applied.

130. In order to understand the thrust caused by

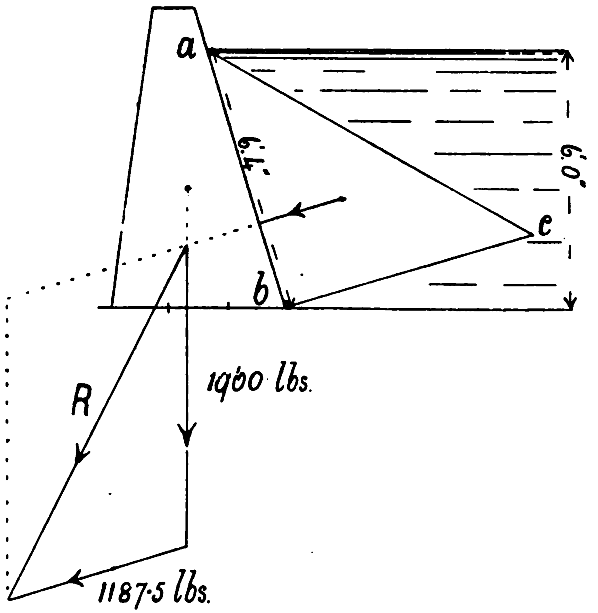


Fig. 68.

earth on a retaining wall a little explanation is necessary.

If a bank of earth be left exposed to the weather, it will crumble and fall until it forms a certain natural *slope* depending upon the nature of the earth of which

it is composed. The angle which this slope forms with the horizontal plane is called the angle of repose.

If in Fig. 69 *A B* shows the natural slope, then *A B C* is the angle of repose. If *B D* be drawn perpendicular to *B C*, the angle *A B D* is the complement of the angle *A B C*.

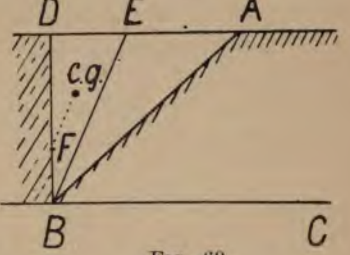


FIG. 69.

It has been shown by several writers that the portion of earth which tends to break away and overturn a wall is that enclosed between the vertical line *B D* from the foot of the wall and the line *B E* bisecting the complement of the angle of repose, that is, in Fig. 54, the portion *D B E*.

B E is called the plane of rupture.

In order that the portion *D B E* should break away, it must slide down the plane *B E*, acting like a wedge on *B D*, and forcing it out horizontally.

It was shown in § 114 that if a body be placed on an inclined plane a certain force is exerted parallel to the plane. Each particle of the mass *D B E* is a body on the inclined plane *B E*, and the sum of them may be treated as if concentrated at the c.g. of *D B E*, hence the whole mass exerts a force through its c.g. parallel to the plane. This intercepts *B D* at *F*, so *F* is the point of application of the force.

This point is always $\frac{1}{3}$ the distance up the wall. *D B E* is evidently prevented from sliding by the friction of the plane acting up *B E* and the horizontal reaction of the wall applied at the point F. This

reaction must be equal to the horizontal thrust of the mass, or the wall will be forced over.

This horizontal thrust is obtained by resolving the vertical force exerted by the mass *D B E* in a horizontal direction and one parallel to the plane.

131. A stone wall is built to retain a bank of ordinary

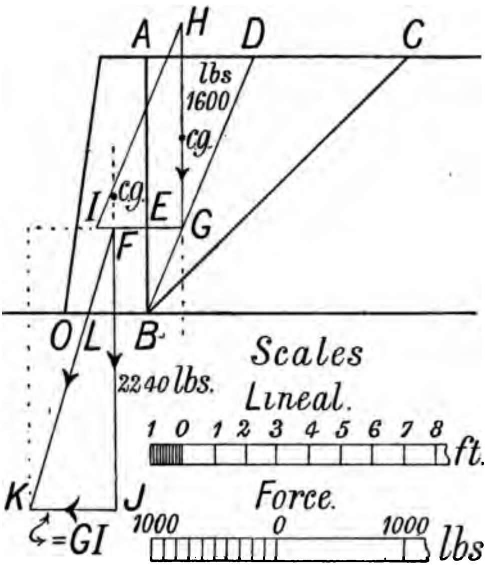


FIG. 70.

earth 8 ft. high and estimated to weigh 120 lbs. per cub. ft. The base of the wall is 2′ 6″, the batter of the outer face is 1 in 8, and the inner face vertical.

If the angle of repose be 45°, determine the position of the resultant force.

Set out the wall to scale as shown in Fig. 70. Draw *the angle of* repose and bisect the complement *A B C*

with the line $B D$. $A B D$ now represents the mass of earth whose horizontal thrust has to be determined.

Through the c.g.'s of the wall and of $A B D$ draw vertical lines. From E, the point of application of the force exerted by $A B D$ (which, as shown before, is $\frac{1}{3}$ of $B A$) draw a horizontal line to intercept these vertical lines at F and G.

The weight of 1 ft. length of the wall is 2240 lbs., and 1 ft. length of the section $A B D$ weighs 1600 lbs.

From G, on the line passing through the c.g. of $A B D$, measure $G H$ equal to the vertical force exerted by $A B D$, i.e. $= 1600$ lbs. From H draw a line parallel to $B D$, meeting the line $G F$ at I. $G I$ now represents the magnitude and direction of the thrust of $A B D$, and its point of application is E.

This line meets the line of action of the force exerted by the wall at F. From F scale off $F J$ equal to this force, i.e. equal to 2240 lbs., and from J draw $J K$ equal and parallel to the thrust $G I$. Join $F K$.

$F K$ now represents the magnitude and direction of the resultant thrust.

This meets the base of the wall at L.

132. If this resultant crosses the base of the wall at any point between B and O, the wall is safe from overturning; if it passes through O, the wall is on the point of overturning; and if it passes outside the point O, the wall will be overthrown, unless the tensile strength at the inner edge is sufficient to prevent it.

133. In considering the stability of retaining walls, there is another point which it may be well to point out, but the explanation of which is beyond this work.

The removal of the resultant force from the centre

causes the pressure on the outer edge to be much increased, and the nearer it is to the edge the greater is this pressure.

The pressure at this point must not be greater than the material of which the wall is composed can safely bear, or the wall will fail by crushing.

134. Polygon of Forces.—Let Fig. 71 represent four forces of which the magnitude and direction of two are known. It is required to determine the other forces.

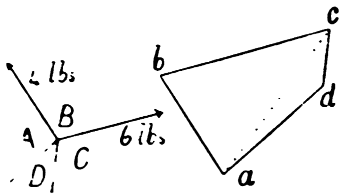


Fig. 71.

Draw *a b* and *b c* to represent the forces *A B* and *B C*. Join *c a*.

c a is now the equilibrant of the two known forces (§ 105), therefore *a c* is the resultant (§ 106), and we may consider this as being substituted for *A B* and *B C*.

We have now three forces (the resultant of the first two, and the two unknown ones) of which one, *a c*, is known, therefore we can find the other two.

From *c* draw a line parallel to *C D*, and from *a* one parallel to *A D*. Let them meet at *d*. Then *c d* and *d a* will give the magnitude and direction of *C D* and *D A*.

It should be noticed that this result could be arrived at without finding the resultant, by drawing the lines *c d* and *d a* from the ends of the lines representing the two other forces. This latter method is the more direct, and is usually adopted.

135. Fig. 72 represents five forces in equilibrium, of which three are known.

It is necessary to find the magnitude of the other two, and the direction in which they act.

Draw $b\,c$ to represent $B\ C$ in direction and magnitude, from c draw $c\,d$ representing $C\,D$ in direction and magnitude, taking care that the sense of each force is in the same direction round the figure, and from d draw $d\,e$ to represent $D\,E$ in direction and magnitude, again noting that the force acts in the direction of d to e.

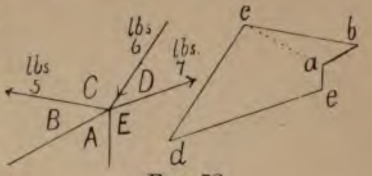


FIG. 72.

From b draw a line parallel to $A\ B$ and from e a line parallel to $E\,A$. Let them meet at a. $e\,a$ and $a\,b$ now represent the magnitude of $E\ A$ and $A\ B$, and, as the sense of the forces must form a circuit round the polygon, e to a and a to b are their respective directions, i.e. $E\ A$ acts upwards, and $A\ B$ upwards towards the right.

136. From the polygon of forces the resultant of any number of forces can readily be obtained.

Let it be required to find the resultant of $A\ B$ and $B\ C$ (Fig. 72). The first and last letters of the names of these forces in clockwise order are A and C. On the force diagram join a and c. Then $a\,c$ fully represents the resultant, that is, the line $a\,c$ gives its magnitude, and its direction is from a to c.

Had it been required to find the resultant of the other three forces, the first and last letters would have been C and A respectively. The resultant force would in this case be represented by $c\,a$, that is, its magnitude is the same but its direction is from c to a.

137. For the solution of forces acting at a point and maintaining equilibrium, there must not be more than

two unknown ones, and of these two, if the direction be known then the magnitude can be found, and, if the magnitudes be known, the directions can be found.

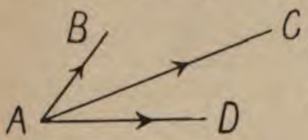
138. If a number of forces keep a body in equilibrium, the polygon representing the forces (i.e. the force diagram) must close, and the senses be concurrent.

139. If one of the senses of the forces in a closed force diagram be opposed to the others, the force represented by it is the resultant of the others.

140. If the force diagram does not close, then the system which it represents is not in equilibrium, and the closing line would represent the magnitude and direction of the resultant, but its sense would be non-concurrent.

Examples to Chapter IV

1. What does $A\,C$ (Fig. 1) represent?

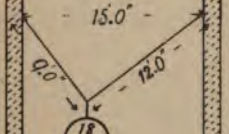


Ex. Ch. IV.—Fig. 1.

What would it be called if its direction were reversed?

2. What is meant by the "resultant of two forces?"

3. If two forces, equal to 5 lbs. and 8 lbs. respectively, act towards a point at an angle with each other of 120°, what force is required to produce equilibrium?



Ex. Ch. IV.—Fig. 2.

4. Fig. 2 represents a piece of cord attached to opposite sides of a room, and supporting a weight.

Find the tension in each section of the cord.

5. A ladder weighing 150 lbs. rests against a smooth vertical wall at an angle of 60° with the horizontal plane.

Find the direction and magnitude of the reaction of the ground.

6. A rafter, inclined at 30° with the horizontal plane, exerts a force equal to 200 lbs.

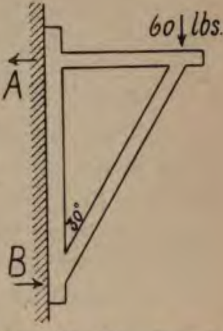
Find the vertical and horizontal reactions of the wall supporting it.

7. A door is 7′ × 3′ 6″, and weighs 250 lbs. The hinges are 7″ and 12″ from the top and bottom respectively.

Find the horizontal reaction of the bottom hinge, and the total reaction of the top one.

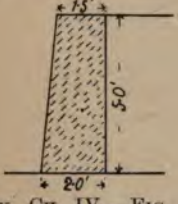
8. Fig. 3 illustrates a bracket supporting a weight of 60 lbs.

(*a*) Find the amount and kind of stress in the horizontal and inclined members.



Ex. Ch. IV.—Fig. 3.

(*b*) Also find the reactions A and B.



Ex. Ch. IV.—Fig. 4.

Ex. Ch. IV.—Fig. 5.

9. Fig. 4 shows a retaining wall supporting a bank of earth. The earth weighs 120 lbs. per cub. ft., and its angle of repose is 45°.

If the wall weighs 140 lbs. per cub. ft., where does the resultant pressure intercept the base of the wall?

10. Fig. 5 represents five forces in equilibrium.

Find the magnitudes and directions of $A B$ and $B C$.

What is the resultant of the three given forces?

CHAPTER V

THE FUNICULAR POLYGON

141. THE FUNICULAR POLYGON.—If a system of forces in equilibrium be applied to a body already at rest, then that body will still remain at rest (§ 32).

Let five forces in equilibrium be applied to a jointed frame as shown in Fig. 73.

This frame is supposed to be such that each bar (or

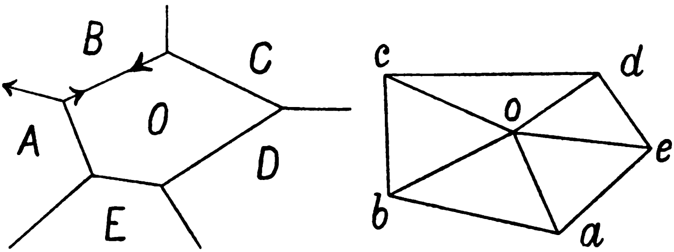


FIG. 73.

link as it is called) will stand either tension or compression, and each joint (or node) is supposed to be hinged so that the bars will accommodate themselves to the best position to withstand the forces applied to them.

Such a frame is called a funicular polygon, and must always close.

Let the force *A B* be known.

As the whole frame is in equilibrium, each node is in equilibrium, and the node on which *A B* is acting

is maintained in equilibrium by the action of that force and the stresses set up in *B O* and *O A*. Draw *a b* equal and parallel to the force *A B*, and draw lines from *a* and *b* parallel to *B O* and *O A*. Then *b o* and *o a* will represent the direction and magnitude of the stresses set up in the links *B O* and *O A*. But at the other end each link will exert an equal and opposite force (§ 92). Taking the node where *B C* acts, we have three forces, but *O B* has just been found and is represented in direction and magnitude by *o b*. By drawing parallel to *B C* and *C O*, *b c* and *c o* are obtained, and these represent the force *B C* and the stress set up in *C O*. Proceeding to the next node, by means of *o c*, *c d* or the force *C D* and the stress *d o* in the next bar are ascertained. By repeating this operation the whole of the forces and the stresses in the bars are obtained.

When completed it will be seen that the lines representing the forces form a closed polygon, proving that the forces represented by these lines are in equilibrium.

142. Further, the lines representing the stresses in the links all meet at the same point. This point is called the pole, and the lines radiating from it polar lines or vectors.

143. If all the forces applied to a funicular polygon, and the direction of two of the links be known, then the funicular polygon can be completed, because from the forces the force diagram can be formed and the intersection of the two lines parallel to these two links will give the pole. The directions of the remaining links are obtained by drawing the other vector lines.

144. If a system of forces be in equilibrium any funicular polygon can be found to which they can be applied.

For, let *a b c d e* (Fig. 74 (*a*)) be a reproduction of the force diagram Fig. 73.

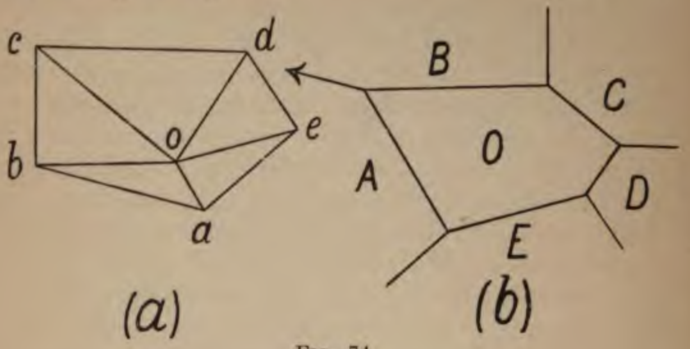


FIG. 74.

Take any pole *o* and draw the vectors.

Draw *A B*, *B O* and *O A* (Fig. 74 (*b*)) parallel to *a b*, *b o*, and *o a*. Mark off *B O* any length, and at its extremity draw *B C* and *C O* parallel to *b c* and *c o*. Cut off *C O* any length, and draw *C D* and *D O* parallel to *c d* and *d o*. Set off *D O* any length, and draw *D E* and *E O* parallel to *d e* and *e o*. Produce *E O* and *A O* to meet, and from this point draw a line *E A* parallel to *e a*.

Fig. 74 (*b*) now represents the same five forces as those in Fig. 73, but they are applied to another funicular polygon.

Hence, if a system of forces be in equilibrium and a force diagram drawn, any pole can be taken, and a funicular polygon found in respect of that pole.

145. Fig. 75 shows a funicular polygon and the forces applied.

It is necessary to find how equilibrium may be maintained in each part if a section be taken at *x y*.

It is evident that the forces on one side of the section

are kept in position by those on the other, hence the resultant of the forces on the one side will maintain equilibrium with the forces on the other.

Draw the force diagram *a b c d e*.

The forces on the left are *E A* and *A B*. Join *e b*, then *e b* is the magnitude of the resultant, and *e* to *b* its direction. (§ 136.)

It is now necessary to find where this resultant acts. By substituting the resultant *e b* for the two forces *E A* and *A B* the force diagram *e b c d e* is obtained. But *o*

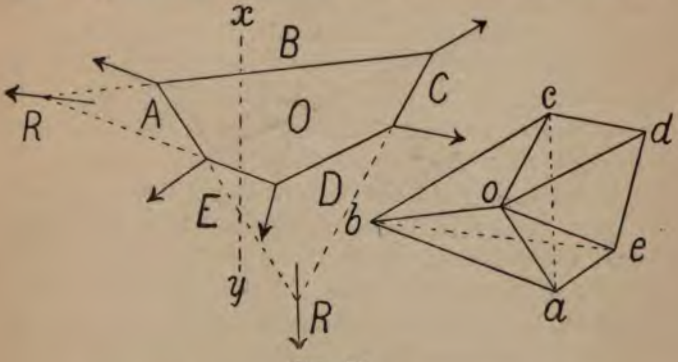


Fig. 75.

is a pole from which the vectors *o b*, *o c*, *o d* and *o e* are already drawn, hence a funicular polygon may be obtained whose sides are parallel to these vectors. On examination it will be seen that *O B*, *O C*, *O D* and *O E* are already parallel to *o b*, *o c*, *o d* and *o e* respectively, but a funicular polygon must close, hence *O B* and *O E* must be produced to meet.

There must be a force acting at each node of a funicular polygon, and each of the forces *B C*, *C D* and *D E* are already acting at a node, hence the remaining force,

which is represented by $e\,b$, must act at the node formed by the production of these lines.

Again, the resultant of the forces $B\,C$, $C\,D$ and $D\,E$ is $b\,e$, that is, the resultant of the forces on the right of the section is of the same magnitude as the resultant of the forces on the left, but it acts in the opposite direction, and by obtaining a new funicular polygon as before, it will be found to act through the same point.

146. Hence, if a section be taken across a funicular polygon, the resultant of the forces on either side will act through the node formed by the production of the intersected sides, and the magnitude and direction of each resultant are found by the force diagram; also, the resultant of all the forces on one side of the section is equal to the resultant of all the forces on the other side, but they act in opposite directions.

147. Similarly the resultant of any of the forces and a point in its line of action may be obtained. Determine the resultant of $C\,D$, $D\,E$ and $E\,A$ (Fig. 75). C and A are the first and last letters in the clockwise notation, so $c\,a$ on the force diagram gives the resultant, and it acts through the point where the links $C\,O$ and $A\,O$ would meet if produced.

This is practically the same thing as taking a section cutting the links $C\,O$ and $A\,O$.

148. Therefore it should be noticed, that the first and last letters of the forces, when named in clockwise order, not only give the magnitude and direction of the resultant force on the force diagram, but also name the links on the funicular polygon whose intersection, when produced, gives a point in the line of action of that resultant.

149. Before applying parallel forces to a funicular

polygon, a little explanation of the force diagram may not be out of place.

If the system be in equilibrium the force diagram must close. (§ 138.)

Suppose a beam loaded and supported as shown in Fig. 76.

Draw *a b*, *b c* and *c d* to represent the known forces *A B*, *B C* and *C D*.

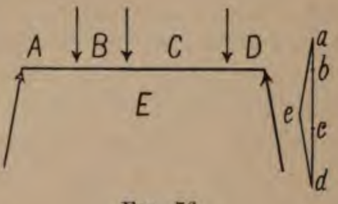


FIG. 76.

From *d* draw a line parallel to *D E*, and from *a* one parallel to *A E*. *d e* and *e a* give the magnitude and direction of the force exerted by the two supports.

Suppose *D E* and *E A* to be vertical, as shown in Fig. 77, then it is evident that the lines *d e* and *e a* will be in a straight line and lie upon *d a*, i.e. *d a* will be the closing line of the force diagram, but the point of intersection is not known, hence the reactions of the two supports are equal to the total load *a d*, but what proportion each bears is not determined.

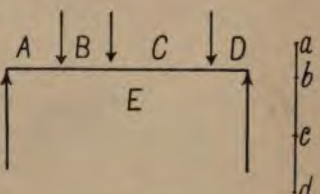


FIG. 77.

The point *e* will, however, lie somewhere between *a* and *d*, and *a b c d a* (Fig. 77) will form a closed polygon in quite the same sense as *a b c d e a* (Fig. 76).

Hence, the force diagram of a system of parallel forces is a straight line.

150. We will now proceed to utilize the funicular polygon to determine parallel forces.

The most common case is that of a simple beam loaded at various points.

Two scales are necessary—a lineal scale to set out the beam and the positions of the loads, and a force scale for all the measurements on the force diagram. Fig. 78 shows a beam with the position and amount of each load.

Taking a convenient force scale $a\,b=3$ cwts., $b\,c=$ 2 cwts., and $c\,d=5$ cwts.; $a\,d$ is now the sum of the

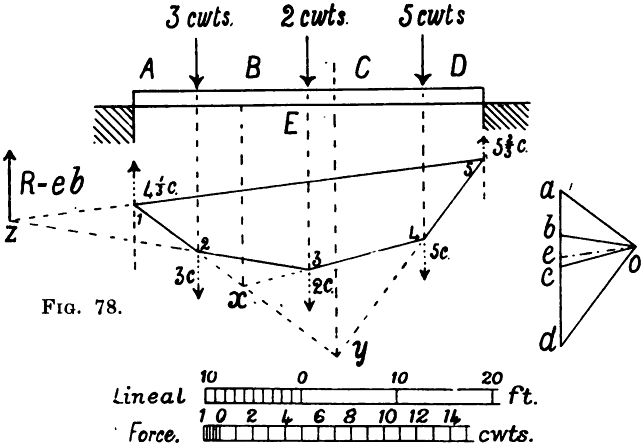


FIG. 78.

loads, and the sum of the reactions is equal to this, therefore $d\,a$ is the closing line of the force diagram.

It is necessary to determine the position of e to ascertain what proportion of the load is borne by each support.

Take any pole o and draw vectors to a, b, c and d.

From any point on the support $E\,A$ draw a line 1–2 parallel to $a\,o$ until it cuts a perpendicular from the first load. From the point 2 the line 2–3 is drawn parallel to $b\,o$ until it intersects the perpendicular from the

second load. From 3 the line 3–4 is drawn parallel to *c o*, till it meets the line of action of the third force, and from this point the line 4–5 is drawn parallel to *d o* as far as the support. Join 1 and 5.

123451 is now a funicular polygon, and to enable the student to compare it with the others, the forces are shown dotted at the nodes.

An examination of the funicular polygon will show that it has five sides, whereas there are only four vectors. A vector must now be drawn parallel to the remaining side of the polygon, and this determines the position of *e*.

d e now represents the magnitude and direction of the reaction *D E*, and *e a* that of *E A*.

151. It will be necessary to know the names of the links of the funicular polygon. The one parallel to *a o* is *A O*, the one parallel to *b o* is *B O*, and so on. It is not necessary to put the names on the polygon, because a glance at the force diagram will at once supply them.

152. The name of each link may also be ascertained by referring to the beam.

As each link is terminated by the lines of action of some two forces, it has, as its distinguishing letter, the one which names the space on the beam between those two forces. Thus the space between the 3 and 2 cwts. is *B*. The link terminated by the perpendiculars from these two forces is known as *B O*.

Again, the space *E* extends from the one support to the other, and the link which crosses this space is *E O*.

153. Find the resultant of *A B* and *B C* (Fig. 78) and a point in its line of action.

The first and last letters in the clockwise sequence are *A* and *C*, therefore *a c* on the force diagram gives the resultant force, which is 5 cwts., and the intersection of

the links $A\,O$ and $C\,O$ gives the point x through which it acts.

A perpendicular from x gives the point on the beam where it acts.

154. Find a point on the beam where the three forces (Fig. 78) could be accumulated without interfering with the reactions.

This is practically asking for the resultant of the three forces and its point of application.

The three forces are $A\,B$, $B\,C$ and $C\,D$, therefore $a\,d$ gives the magnitude and direction of the resultant force, and y the intersection of the links $A\,O$ and $D\,O$ gives a point in its line of action. A perpendicular to the beam from y will give the point where the 10 cwts. would be placed.

155. Ascertain the force which could be substituted for $A\,B$ and the reaction on the left, and the point where it should be applied.

The sequence is $E\,A$ and $A\,B$, hence $e\,b$ on the force diagram gives the direction and magnitude of the force, and z, where the links $E\,O$ and $B\,O$ meet, is a point through which it acts.

Of course, the student should note that, having drawn the lines of action of these resultant forces through the beam, the distance of these points from either end can be obtained by applying the lineal scale.

156. It was pointed out in Chapter II that questions on the three orders of levers could be solved by means of similar triangles.

The knowledge of the funicular polygon supplies an easier and more interesting method of solving them, as the following examples will show :

A lever of the first order supports a weight of 60 lbs.,

1′ 6″ from the fulcrum. Find the power necessary to balance this if the power arm be 2 ft.

Set out the lever with the position of the weight, etc., to a convenient lineal scale (Fig. 79) and adopt a force scale.

Draw $a\,b$=60 lbs., and take any pole o. Join $a\,o$ and $b\,o$. Draw the link $A\,O$ across the space A, and the link $B\,O$ across the space B, and parallel to $a\,o$ and $b\,o$ respectively. Close the polygon, and draw the vector $c\,o$ parallel to the closing line. Let $o\,c$ terminate in $a\,b$

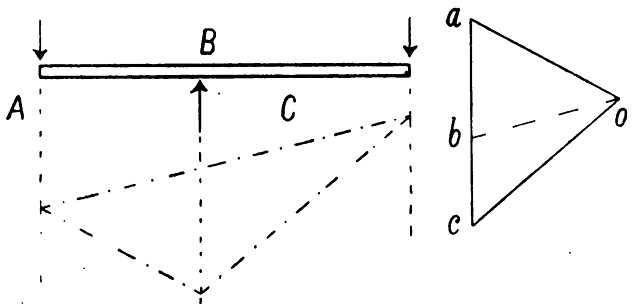


FIG. 79.

produced. Then $b\,c$ is the required power, which is 45 lbs.

157. A lever is 6 ft. long. Where is the fulcrum if a force of 15 lbs. supports a weight of 50 lbs.?

Draw the lever=6′ (Fig. 80) and with a convenient force scale draw $a\,b$=50 lbs. and $b\,c$=15 lbs. Join a, b, and c to any pole o. Draw the link $B\,O$ across the space B and parallel to $b\,o$. From the ends of this draw the links $A\,O$ and $C\,O$ parallel to $a\,o$ and $c\,o$ and across the spaces A and C respectively.

A perpendicular from the point of intersection of these links will give the position of the fulcrum.

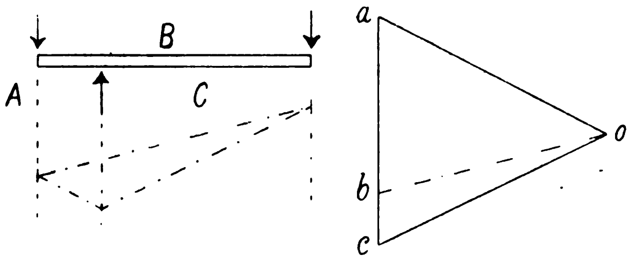


FIG. 80.

158. Fig. 81 shows a lever with the relative positions of the fulcrum, weight, and power.

What weight will a power equal to 24 lbs. sustain ?

Draw $c\ a$=24 lbs. Take a pole and draw the vectors $c\ o$ and $a\ o$. Across the space A draw the link $A\ O$ parallel to $a\ o$, and across the space C the link $C\ O$ parallel to $c\ o$.

Close the polygon, and draw $o\ b$ parallel to the link $B\ O$ thus formed.

$a\ b$ represents the weight drawn to scale.

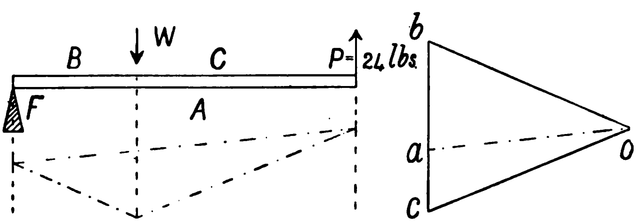


FIG. 81.

159. A lever 6 ft. long, weighs 20 lbs. If a weight of 80 lbs. be placed 2 ft. from the fulcrum, which is at the end, find the power necessary at the other end to support *it.* The weight of the lever acts at its centre of gravity.

Fig. 82 shows the lever and the position of the forces.

Draw the forces *a b* and *b c* and the three vectors.

Draw the links as before, and close the polygon. The closing line indicates how the vector *o d* is to be drawn.

c d is the power drawn to scale.

160. Reactions of the supports of framed structures.—It should be noted in the case of a simple beam that the proportion of a load borne by each support is in the inverse ratio to the perpendicular distance of its line of action from the support.

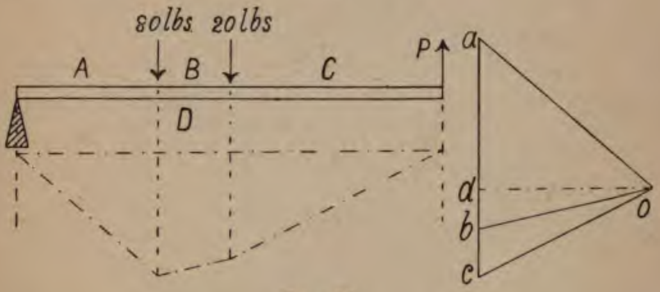


Fig. 82.

The same rule holds good for framed structures of every description, hence the reactions on their supports can be found in a similar manner.

To prove this we will take one simple example and compare the results arrived at graphically and arithmetically.

Fig. 83 illustrates a roof truss with a load of 6 cwts. at the ridge.

The reactions *B C* and *C A* are given by *b c* and *c a* on the force diagram, which are found to represent $3\frac{1}{2}$ cwts. and $2\frac{1}{2}$ cwts. respectively.

161. The span shown in the figure is 12 ft. and the

line of action of the 6 cwts. is 7 ft. from x and 5 ft. from y.

Taking the moments about x, we have the reaction of $BC \times 12' = 6$ cwts. $\times 7'$, therefore the reaction of $BC = \frac{6 \text{ cwts.} \times 7'}{12'} = 3\frac{1}{2}$ cwts.; and taking the moments about y, we have the reaction of $CA \times 12' = 6$ cwts. $\times 5'$, therefore the reaction of $CA = \frac{6 \text{ cwts.} \times 5'}{12'} = 2\frac{1}{2}$ cwts.

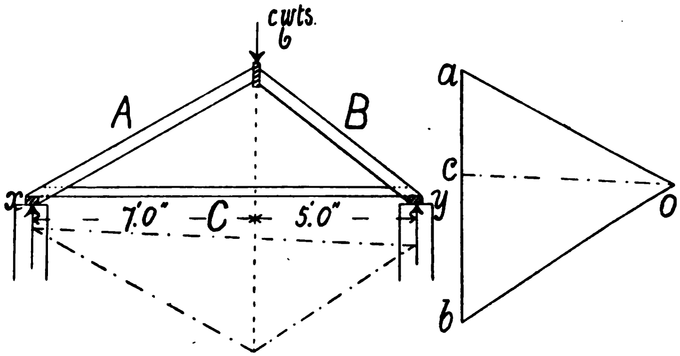


Fig. 83.

It will thus be seen that the results obtained graphically correspond with those found arithmetically.

162. The advantage of the graphic method over the arithmetical one for finding the reactions of the supports is quite apparent, when it is pointed out that the former method is the same for all kinds of structures, whereas the latter often involves difficult calculations.

In order to show the application of the graphic method a few typical cases are given. As the method of procedure is exactly the same as that for a simple beam, only the points not previously noted will be commented upon.

163. Suppose a truss as shown in Fig. 84 carrying an evenly distributed load of 3 tons on the top beam.

Find the reactions at the supports.

As the load is evenly distributed along the entire length of the beam, it may be considered as being accumulated at its centre, or as being transmitted by the beam to the joints, one-half being on each.

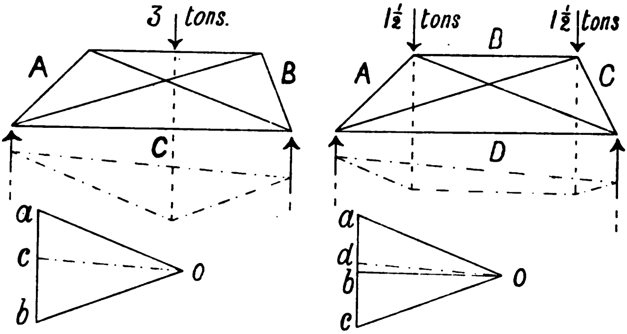


FIG. 84.

Both cases are worked out, and it should be noticed that the result is the same in each case.

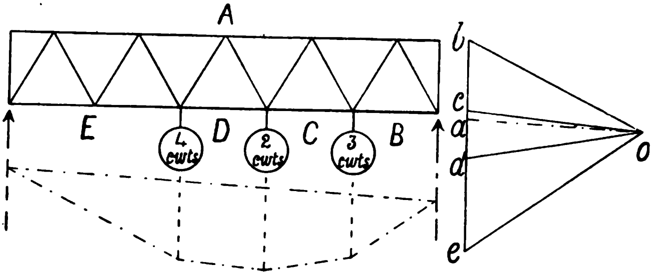


FIG. 85.

Fig. 85 shows a Warren girder with three loads on the bottom boom.

Fig. 86 is a diagram of a short N girder with two loads on the top boom.

164. Before proceeding with the roof truss it is necessary to understand what the load is composed of, and how it is transmitted to the truss.

The load consists of the weight of the truss itself, the weight of the covering, snow, and wind pressure. The weight of the covering depends on its nature. The wind pressure is not vertical, but its vertical component can be found.

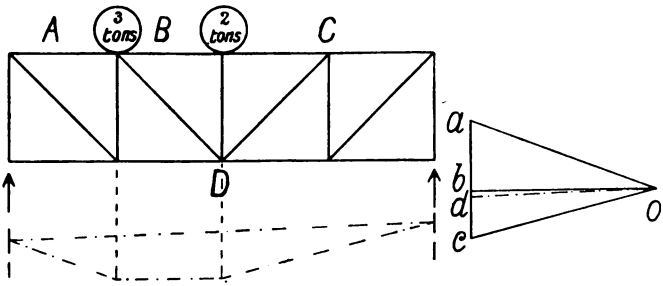


Fig. 86.

The student may assume that the total vertical load on a roof is 56 lbs. per square foot of the external sloping surfaces.

Suppose a space 30′ × 24′ to be roofed. Fig. 87.

This would necessitate two king-post trusses at 10′ centres. These with the ridge and purlins would divide the roof into 12 equal spaces.

Taking the rise to be $\frac{1}{3}$ of the span, the slope would measure nearly $14\frac{1}{2}$ ft. The area of each slope would be $14\frac{1}{2}' \times 30' = 435$ sq. ft.

The total weight would then be (2×435) half cwts., or 435 cwts.

This is spread over 12 spaces, so the weight of each $=\frac{435}{12}$ cwts. $=36\frac{1}{4}$ cwts.

Taking the spaces A and D, the common rafters transmit half of the loads to the wall-plates and half to the purlins. Taking the spaces B and C, half the weight on each is transmitted to the purlins, and the

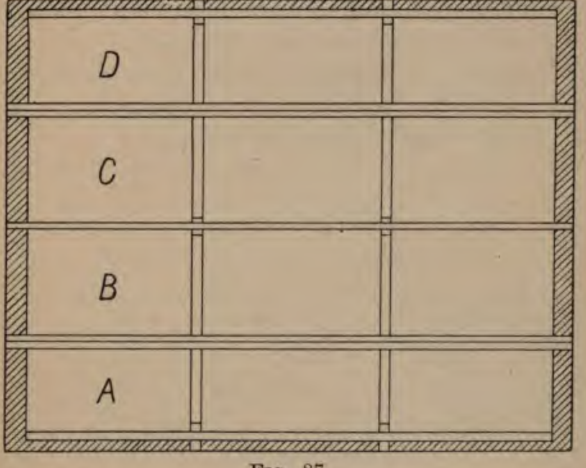


FIG. 87.

other half to the ridge. Thus the ridge and each purlin get $36\frac{1}{4}$ cwts. and each wall-plate $18\frac{1}{8}$ cwts.

But the purlins and ridge are beams with distributed loads, one end of each being supported by the wall, and the other by the truss, hence the truss supports half the load on each. In the same manner it can be shown that the same truss supports a like amount from the adjoining spaces.

Therefore, in the above example, the purlins and ridge

transmit 36¼ cwts. each to the truss and 18⅛ cwts. comes directly on each wall, and the ridge, purlins, and walls are the points of application of these loads.

165. If the roof be symmetrically planned, the magnitude of the loads at the different points of the truss can be obtained as follows :—

Divide the total weight of the roof by the number of spaces into which the trusses divide it, and the weight thus obtained is again divided, so that each purlin and ridge gets twice as much as each wall.

166. If a roof truss be symmetrical and symmetrically loaded, the reactions of the supports will be equal, each equal to half the sum of the loads.

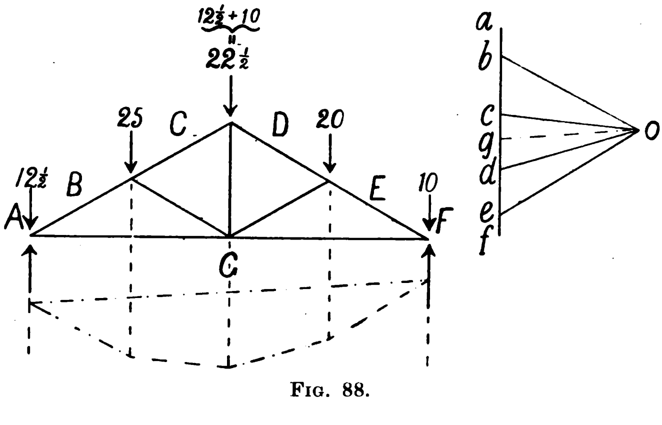


FIG. 88.

167. As an application of the funicular polygon to a roof truss Fig. 88 is given. It shows a total load of 50 cwts. on one side, and a load of 40 cwts. on the other. It should be carefully noted how these loads are applied to the truss.

Letter the spaces between the external forces, and draw the line of loads *a b c d e f*.

The loads *A B* and *E F* come directly on the wall, and are entirely independent of the truss.

What we have to find out is what proportion of the loads *B C*, *C D* and *D E* each wall bears, and for this purpose our line of loads is *b c d e*.

Take a pole and join *b*, *c*, *d*, and *e* to it. Make a funicular polygon with the links parallel to these vectors, and draw *o g* parallel to the closing link.

e g now represents the proportion of the three loads borne by the wall *F G*, but in addition to this, it supports the load *E F* which is represented by *e f*, therefore the total reaction of the wall *F G* is shown by the line *f g*.

Similarly *g a* represents the total reaction of the wall *G A*.

168. Since the resultant of all the forces exerted by a body passes through its c.g., and since the funicular polygon proves the most convenient method of obtaining the resultant of a number of parallel forces, it can be applied to find the c.g. of a body which has to be divided into a number of segments.

Suppose it is required to find the c.g. of the section shown in Fig. 89.

Divide the figure into three parts as shown, and find the c.g. of each portion. The weight of each part may now be considered as accumulated at its c.g., and acting in a vertical direction.

Through the c.g. of each draw vertical lines. *D E* now gives the line of action of a force which is equal to the weight of the bottom portion ; *E F* gives the line of action of a force which is equal to the weight of the

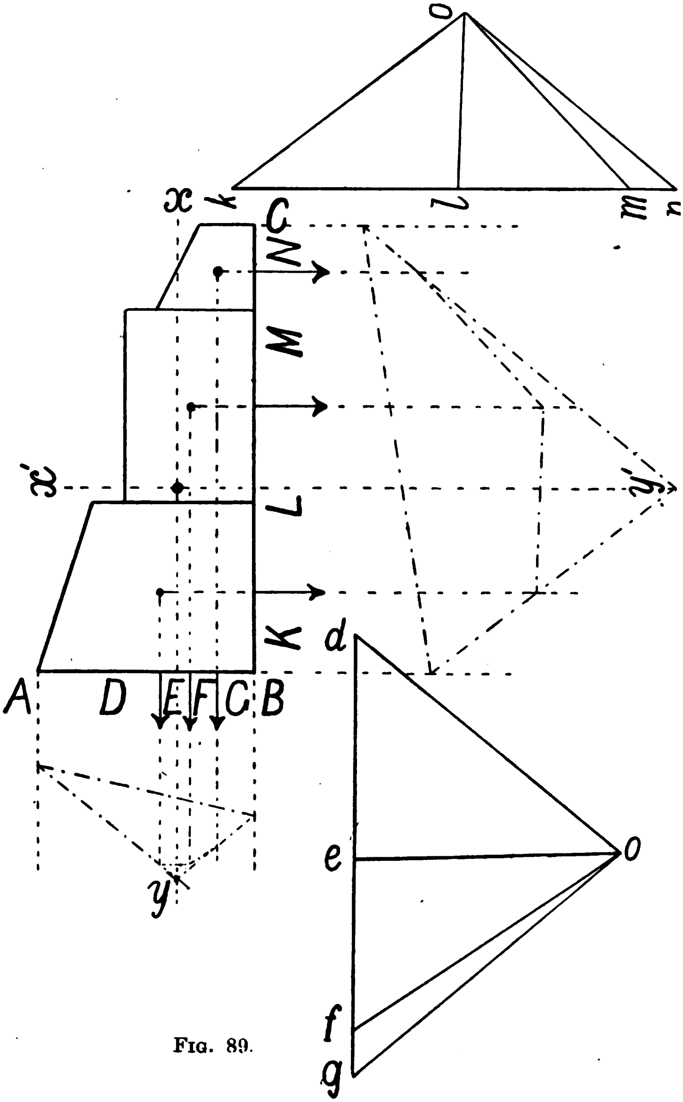


FIG. 89.

middle portion; and $F G$ the line of action of a force equal to the weight of the top portion.

Draw a force diagram making $d e$ equal to the weight of the bottom portion, $e f$ equal to the weight of the middle portion, and $f g$ equal to that of the top portion. Take any pole and draw the funicular polygon.

The forces are represented by $D E$, $E F$, and $F G$, therefore the resultant force is $d g$, and the intersection of the links $D O$ and $G O$ will give a point in its line of action.

Let them meet at y. Through this point draw the perpendicular $x y$, then the c.g. is in this line, and the resultant force of the whole mass acts along it.

All that is required for present use is the magnitude of the resultant force and its line of action. The above method will give it whatever be the number of segments into which the figure is divided.

Should it be required to ascertain where in the line $x y$ the c.g. is situated, the whole figure may be considered as lying on the side $B C$.

In this case $K L$, $L M$, and $M N$ would give the directions and positions of the forces exerted by the bottom, middle, and top portions respectively.

By drawing a new force diagram, and proceeding as before, $x'y'$ is obtained, and the c.g. of the whole figure is at the point where this intersects $x y$.

Examples to Chapter V

1. A beam rests on two supports, A and B, 10 ft. apart. If a load of 15 tons be placed 3 ft. from B, what are the reactions of the supports?

2. A girder weighing 1 ton, and 15 ft. long, carries a

load of $1\frac{1}{2}$ tons 4 ft. from one end, and another of 2 tons 5 ft. from the other end.

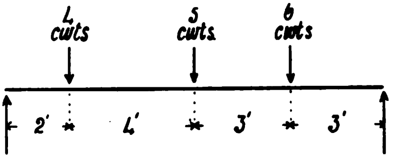
Find the total load on each support.

3. A beam weighing 75 lbs., and 9 ft. long, is supported on two props.

If a weight of 25 lbs. be placed 3′ 6″ from one end, what are the thrusts of the props ?

4. A beam rests on two walls 12 ft. apart. If it weighs 90 lbs., where must a weight of 60 lbs. be placed so that the one wall will carry twice as much as the other ?

5. Fig. 1 shows a beam supporting three weights.



Ex. Ch. V.—Fig. 1.

At what point could they be accumulated so as not to interfere with the reactions ?

6. A rod 6 ft. long, and weighing 3 lbs., acts as a lever, the fulcrum being 2 ft. from one end.

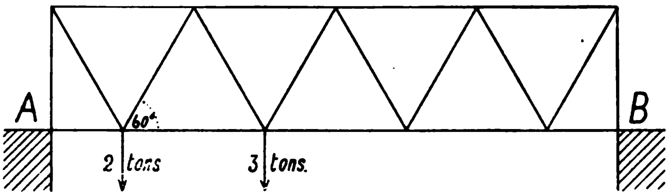
If a 6 lb. weight be placed at the end of the shorter section, what weight must be placed at the other end of the bar to balance it ?

7. A king-post truss carries a distributed load of 5 tons.

Draw a line diagram of the truss, and indicate the amount of load at each point of support. Span=25 ft. ; pitch=30°.

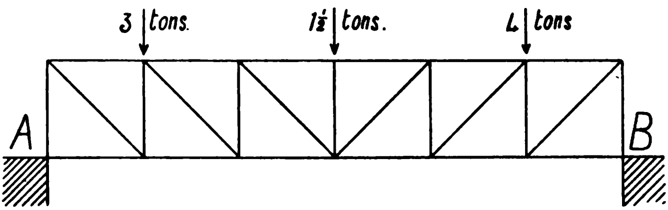
8. Fig. 2 shows a girder loaded at two points.

Find the reactions of A and B.



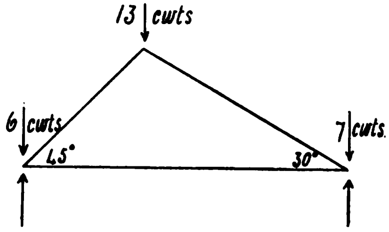
Ex. Ch. V.—Fig. 2.

9. Find the reactions due to the three loads shown in Fig 3.



Ex. Ch. V.—Fig. 3.

10. Find the total reaction of each support due to the three loads shown in Fig. 4.



Ex. Ch. V.—Fig. 4.

Chapter VI

BENDING MOMENTS, AND SHEARING FORCE

169. In Chapter II it was explained what Bending Moment (B.M.) means, and how to find it arithmetically.

We will now proceed to find it graphically. We will take the case of a simple beam loaded at different points, as shown in Fig. 90.

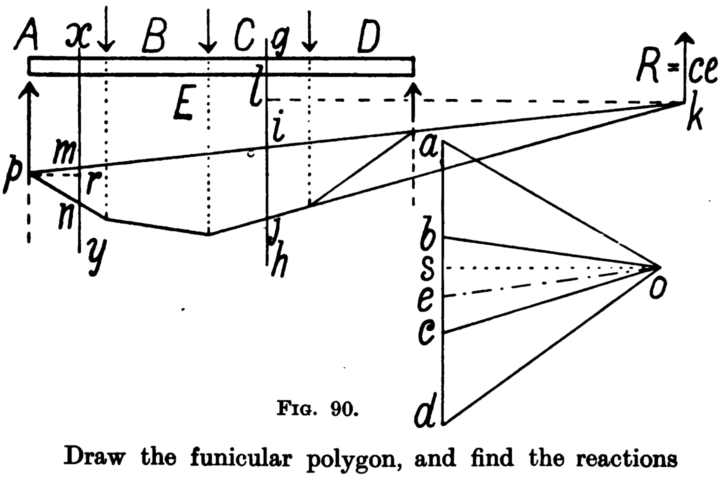


Fig. 90.

Draw the funicular polygon, and find the reactions as shown in the last chapter.

First, let it be required to find the moment about x. Draw the perpendicular $x\,y$, cutting the funicular polygon in m and n.

Now the resultant of all the forces on one side of

x is equal to the resultant of all the forces on the other side (§ 145).

There is only one force on the left of x, so $E\,A$ is the resultant, and $e\,a$ on the force diagram represents this.

Taking the triangles $m\,n\,p$ and $e\,a\,o$, since $m\,n$ is parallel to $e\,a$, $p\,m$ parallel to $e\,o$, and $p\,n$ parallel to $a\,o$, these two triangles are similar in every respect.

Draw the perpendiculars $p\,r$ and $o\,s$ from p and o to $m\,n$ and $e\,a$ respectively.

Then $m\,n \;:\; p\,r \;::\; e\,a \;:\; o\,s$

and $e\,a \times p\,r = m\,n \times o\,s$.

But $e\,a$ is the force $E\,A$ and $p\,r$ is its perpendicular distance from the point x.

Therefore $e\,a \times p\,r =$ the moment of all the forces about x.

But $e\,a \times p\,r = m\,n \times o\,s$,

therefore $m\,n \times o\,s =$ the moment of all the forces about x.

$m\,n$ is the perpendicular distance across the funicular polygon directly beneath x, and $o\,s$ is the perpendicular distance of the pole from the line of loads.

Next, let it be required to find the moment about g.

Draw the perpendicular $g\,h$, meeting the funicular polygon in i and j.

The forces on the right of this section are $C\,D$ and $D\,E$, therefore the resultant is represented by $c\,e$, and it acts where the links $C\,O$ and $E\,O$ meet, that is at k (§ 145).

Because $i\,k$ is parallel to $e\,o$, $j\,k$ parallel to $c\,o$, and $j\,i$ parallel to $c\,e$, the two triangles $j\,i\,k$ and $c\,e\,o$ are similar.

Draw $k\,l$ perpendicular to $g\,h$.

Then $j\,i : k\,l :: c\,e : o\,s$,
and $c\,e \times k\,l = j\,i \times o\,s$.

Since $c\,e$ is the resultant of the forces on one side of g, and $k\,l$ the perpendicular distance of its point of application from the section,

therefore $c\,e \times k\,l =$ the moment of the resultant of $C\,D$ and $D\,E$ about the point g,

or, $c\,e \times k\,l =$ the moment of $C\,D$ and $D\,E$ about g (§ 44).

But $c\,e = e\,c$, and $e\,c$ is the resultant of $E\,A$, $A\,B$, and $B\,C$,

therefore $c\,e \times k\,l =$ the moment of $E\,A$, $A\,B$, and $B\,C$ about g.

Again, $c\,e \times k\,l = j\,i \times o\,s$,

therefore $j\,i \times o\,s =$ the moment of $C\,D$ and $D\,E$ about g,

and $j\,i \times o\,s =$ the moment of $E\,A$, $A\,B$ and $B\,C$ about g.

But $j\,i$ is the perpendicular distance across the funicular polygon directly beneath the point g, and $o\,s$ is the perpendicular of the pole from the line of loads.

$o\,s$ is called the "polar distance."

It is now evident that the B.M. at any part of the beam is given by multiplying the perpendicular across the funicular polygon beneath that point by the polar distance.

But for any one funicular polygon the polar distance is constant, therefore the B.M. varies directly as the perpendiculars (or ordinates) across the polygon.

For this reason the funicular polygon is called the Bending Moment diagram.

170. The ordinates of the B.M. diagram must be

measured with the lineal scale, but the polar distance, being on the force diagram, must be measured with the force scale.

171. Up to the present the pole has been taken at any point, but it will now be seen that, if the bending moment is required, it is advisable to place it so that its perpendicular distance from the line of loads will represent a definite number of lbs., cwts., or tons.

172. It will also be noticed that it would be much more convenient if a scale could be found with which the bending moment could be measured directly off the ordinates, instead of measuring the ordinates with the lineal scale and multiplying this by the polar distance.

Suppose in Fig. 89 that *o s* represents 4 cwts., and that the lineal scale is $\frac{1}{4}'' = 1$ ft., then if an ordinate measures 1″ it represents 4 ft., but this must be multiplied by 4 cwts., so an ordinate of 1″ represents a bending moment of 4 ft. $\times$ 4 cwts, or 16 ft.-cwts.

This gives a new scale of $1'' = 16$ ft.-cwts., by which the moment can be measured directly off the Bending Moment diagram.

173. This new scale is called the "Bending Moment scale," and is obtained by multiplying the lineal scale by the polar distance expressed in lbs., cwts., or tons.

In (§ 172) a bending moment scale of $1'' = 16$ ft.-cwts. was obtained. This is not a convenient scale with which to read off the bending moment by applying the rule to the diagram.

To obtain a B.M. scale such that the bending moment can be read off directly, the polar distance must be taken as 1, 5, 10, 50, or 100, etc. (lbs., cwts., or tons).

Let the lineal scale in Fig. 90 be $\frac{1}{4}'' = 1$ ft., and *o s* (the polar distance) $= 5$ cwts.

Then the B.M. scale is lineal scale × polar distance, that is $\frac{1}{4}'' = 1$ ft. × 5 cwts. = 5 ft.-cwts., or B.M. scale is $\frac{1}{2}'' = 10$ ft.-cwts.

Again, suppose the lineal scale to be $\frac{3}{4}'' = 10'$, and the polar distance 10 lbs.

Then the B.M. scale is $\frac{3}{4}'' = 10$ ft. × 10 lbs.,

or B.M. scale is $\frac{3}{4}'' = 100$ ft.-lbs.

By judiciously selecting the polar distance, as shown above, a decimally divided scale is obtained, with which the readings can be taken directly off the diagram, as explained in Chapter I.

174. *Example.*—A beam is 20 ft. long and loaded with 6 cwts. 4 ft. from one end, and 8 cwts. 5 ft. from the other.

Find the greatest B.M. and the B.M. at the centre.

Adopt two scales (say $\frac{1}{8}'' = 1$ ft. and $\frac{1}{2}'' = 10$ cwts.).

Set out the beam with the positions of the loads and draw the line of loads (Fig. 91).

Place the pole any convenient distance from this (say 15 cwts.); draw the vectors and B.M. diagram.

Then the Bending Moment scale

= Lineal scale × polar distance

$= \frac{1}{8}'' = 1$ ft. × 15 cwts. = 15 ft.-cwts.

$= \frac{1}{12}'' = 10$ ft.-cwts.

With the Bending Moment scale measure the ordinates at the widest part of the B.M. diagram and at the centre.

These represent a bending moment of 36 ft.-cwts. and 32 ft.-cwts. respectively.

The greatest B.M. is at the point where the 8 cwts. is placed, and it should be noticed that it is always underneath one of the loads.

175. *Problem.*—A beam 16 ft. long is supported at both ends. A load of 12 cwts. is placed 3 ft. from one

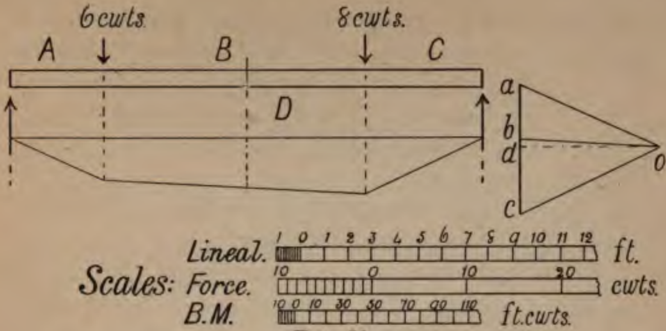


FIG. 91.

end, a load of 10 cwts. is placed 4 ft. from the other, and a load of 15 cwts. is placed at the centre.

Find : 1. The reactions of the supports,

2. the greatest bending moment,

3. the moment of the 12 cwts. about the centre,

4. the moment of the three loads about the centre.

Taking two scales, such as $\frac{1}{8}'' = 1$ ft. and $\frac{3}{8}'' = 10$ cwts., set out the beam (Fig. 92), and draw the force and B.M. diagrams.

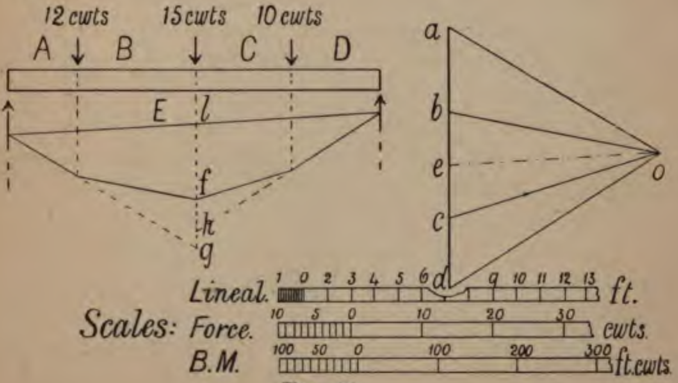


FIG. 92.

The B.M. scale = Lineal scale $\times$ polar distance.

$= \frac{1}{8}'' = 1$ ft. $\times$ 30 cwt. = 30 ft.-cwt.

$= \frac{1}{24}'' = 10$ ft.-cwt.

1. The reactions of $D\,E$ and $E\,A$ are represented by $d\,e$ and $e\,a$ on the force diagram and are 17·25 cwts. and 19·75 cwts. respectively.

2. The greatest B.M. is at the centre, and is represented by $l\,f$, which scales 98 ft.-cwts.

3. Note that the first and last letters of the 12 cwt. load are A and B. The moment of $A\,B$ at the centre will, therefore, be represented by the length of the ordinate from the centre intercepted between the links $A\,O$ and $B\,O$.

Referring to the diagram, it will be seen that the link $A\,O$ does not extend as far as the perpendicular. It must be produced until it does, thus cutting off the ordinate $f\,g$, which scales 60 ft.-cwts.

4. The three loads constitute the three forces $A\,B$, $B\,C$, and $C\,D$, the first and last letters of which are A and D. The moment of these about the centre will be represented by the portion of the perpendicular from the centre intercepted between the links $A\,O$ and $D\,O$.

The link $D\,O$ must be produced until it meets the perpendicular at h.

$h\,g$ gives the required moment, which is 20 ft.-cwts.

176. The Bending Moment diagrams can be applied to beams supported at one end (cantilevers) as well as to beams supported at both ends.

Fig. 93 shows a cantilever loaded at the outer end. It is required to draw the B.M. diagram.

Draw the load line $a\,b$, and select a pole.

(In the case of cantilevers it is more convenient to place the pole so that the closing line of the B.M.

diagram will be horizontal. To obtain this, the pole is placed opposite the top or bottom of the line of loads.)

Draw the vectors $a\,o$ and $b\,o$. From any point on the support draw the link $A\,O$ parallel to $a\,o$ until it intercepts the line of action of the load. From this point draw the link $B\,O$ parallel to $b\,o$. The triangle thus formed is the B.M. diagram, and from it the moment at any part of the beam can be obtained by dropping perpendiculars as previously shown.

In the case of a cantilever with the single load, the B.M. can be much more conveniently found by multiplying the load by its distance from the point selected.

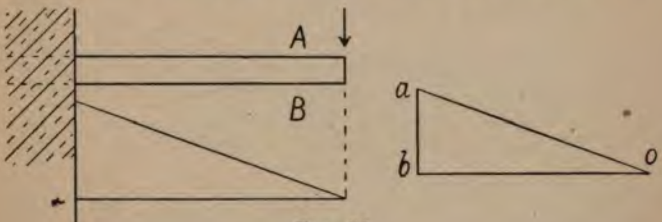


FIG. 93.

Thus, if the load be 5 cwts., and the cantilever 8 ft., the B.M. at the wall end is 8 ft. × 5 cwts., or 40 ft.-cwts., and 2 ft. from the wall it is 6 ft. × 5 cwts., or 30 ft.-cwts.

177. *Problem.*—A cantilever 8 ft. long supports a load of 3 cwts. at its centre., 2 cwts. at its outer end, and 1 cwt. midway between these.

It is required to find—

(*a*) the greatest bending moment,

(*b*) the resultant of the 3 cwts. and 1 cwt., and its point of application,

(*c*) the resultant of the three loads and its point of application,

and (*d*) what load can be placed at the end of the beam to produce the same strain at the wall end as that caused by the three loads.

Having decided upon the scales, set out the beam as shown in Fig. 94. Draw a line of loads and select a

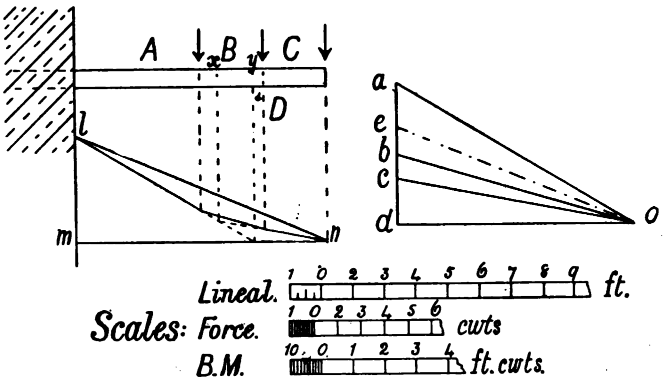


FIG. 94.

pole. Join *a*, *b*, *c*, and *d* to *o*, and draw the links *A O*, *B O*, *C O* and *D O* parallel to *a o*, *b o*, *c o* and *d o* respectively. The figure thus obtained is the Bending Moment diagram.

(*a*) A glance will show that the greatest B.M. is at the wall end, and this measured by the B.M. scale gives 34 ft.-cwts.

(*b*) The two loads are *A B* and *B C*, therefore *a c*, which is equal to 4 cwts., is the resultant, and this acts where the links *A O* and *C O* meet. A perpendicular from this point to the beam gives the point *x*, $4\frac{1}{2}$ ft. from the wall.

(*c*) The three loads are *A B*, *B C* and *C D*, therefore the resultant is represented by *a d*, which equals

6 cwts., and the intersection of the links *A O* and *D O* gives a point in its line of action. A line through this point parallel to *a d* gives the point *y* on the beam, $5\frac{2}{3}$ ft. from the wall.

(*d*) With the load to be substituted, the B.M., *l m*, is to remain the same. Since the same pole can be used, the link *D O* remains. Join *l n*. Then *l m n* is the new B.M. diagram.

From *o* draw a vector parallel to *l n*. Let this meet the load line at *e*.

e d is the new load, which is equal to $4\frac{1}{4}$ cwts.

178. BENDING MOMENT WITH DISTRIBUTED LOADS.—We have now to consider the strain caused by an evenly distributed load.

We will first draw a B.M. diagram as if the whole load *x y* were concentrated at the centre of the beam (Fig. 95).

The triangle *p q r* is this diagram.

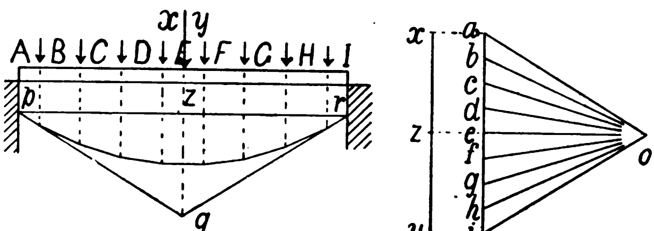


FIG. 95.

Now divide the load *x y* into a number of equal parts, and place them at equal distances apart on the beam.

Draw the vectors and complete the B.M. diagram.

It will be seen that the B.M. is much less at the centre when the load is so split up, and that the links appear to form the chords of a curved line. If the load had

been divided into a greater number of equal parts equidistantly placed, this would have been more apparent still.

But the limit to the division of a load is to evenly distribute it along the entire length of a beam, and in that case the B.M. at the centre is one-half what it would be if the load were concentrated at the centre, and the links would form one continuous curve of a parabolic form with the vertex at the centre.

179. In order, then, to draw the B.M. diagram for a beam with a distributed load, we must know how to draw a parabola.

To show this we will take an example. Fig. 96 shows

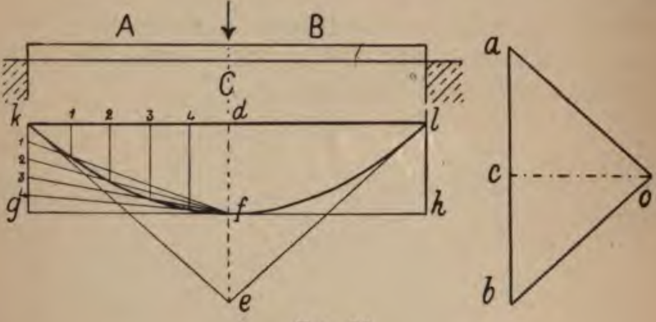


FIG. 96.

a beam with an evenly distributed load which is equal to *a b* on the force diagram.

Draw the B.M. diagram *k e l* as if the whole load were at the centre.

Bisect *d e* at *f*, and through *f* draw *g f h* parallel to *k l*, and complete the parallelogram *k g h l*.

Divide *k g* into any number of equal parts, and join each point to *f*. Divide *k d* into the same number of

equal parts, and from each point thus obtained, drop perpendiculars.

By numbering the points in both directions from k, as shown, the perpendicular from 1 should meet the line $1\,f$, the perpendicular from 2 should meet $2\,f$, and so on. A curved line through these intersections forms the figure $k\,d\,f$, which is half the parabola, and is half the required B.M. diagram.

The other half can be drawn in the same way, but, since the diagram will be symmetrical, this is unnecessary. If the B.M. be wanted at any point on the second half of the beam, a point can be taken similarly placed on the first half and the B.M. at that point ascertained.

Of course, the bending moment at any point is ascertained from the diagram as previously shown, i.e. by finding the B.M. scale and measuring the ordinate beneath that point.

180. A cantilever with a distributed load gives, like the beam, a maximum B.M. equal to one-half what it would be if the load were concentrated at the farthest point from the support.

Fig. 97 is given as an illustration.

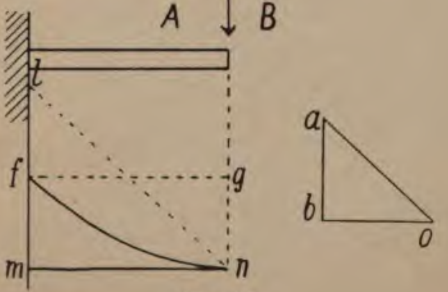


Fig. 97.

Set out the cantilever to scale, and draw *a b* equal to the total load. Select a pole, draw the vectors, and the bending moment diagram *l m n*.

l m gives the B.M. at the wall if the total load were concentrated at the end. Bisect this in *f*, and complete the parallelogram *m f g n*.

Draw the semi-parabola *m f n* as explained in § 179, then *m f n* is the B.M. diagram.

It should be noticed that in whatever form a cantilever is loaded, the B.M. at the unsupported end is nil, and that it increases as the wall is approached, reaching its maximum at that end.

181. Cantilevers and beams supported at both ends may have concentrated and distributed loads at the same time. If the weight of the beams themselves be considered, then there is always a distributed load.

A B.M. diagram of a cantilever under the two systems of loading is shown in Fig. 98.

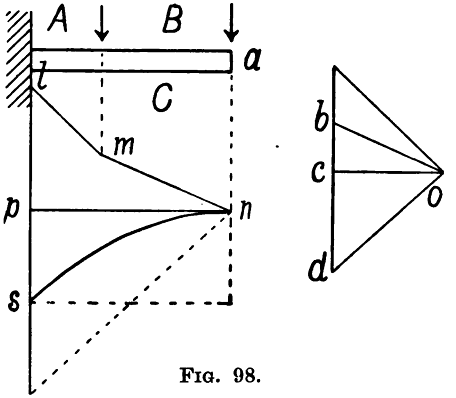


FIG. 98.

The figure *l m n p* is the B.M. diagram for the two concentrated loads, and the figure *s p n* the B.M.

diagram for the uniformly distributed load which is represented by $c\,d$ on the line of loads.

In order to find the B.M. at any point, verticals must be drawn across the figure $s\,l\,m\,n$ and measured as before on the bending moment scale.

182. Fig. 99 shows the B.M. diagram for two concentrated loads and a uniformly distributed load on a beam supported at both ends.

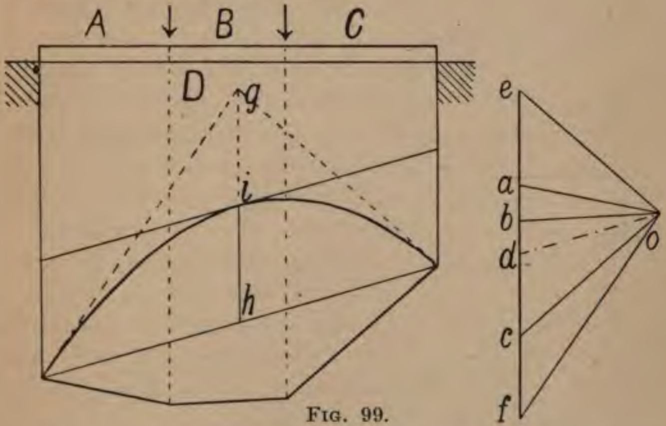


FIG. 99.

The B.M. diagram for the concentrated loads is drawn as already explained. This diagram being below the closing link, it will be necessary to place the B.M. diagram for the distributed load above it. On the line of loads set off $d\,e$ and $d\,f$, each equal to one-half of the distributed load. $e\,f$ will then be equal to the whole distributed load.

From the ends of the closing link draw links parallel to the vectors $e\,o$ and $f\,o$. The perpendicular $g\,h$ would give the B.M. at the centre if the whole of the distributed load were concentrated there. Bisect $g\,h$ in i,

and with the closing link as the chord make a parabola passing through the point i. This parabola, together with the B.M. diagram for the concentrated loads, gives the required Bending Moment diagram.

183. SHEARING FORCE.—It has been shown that a load placed on a beam tends to produce rotation, which tendency is called "the bending moment." A load placed on a beam, besides tending to produce rotation, also tends to cause one portion to slide vertically past another, as shown in Fig. 100.

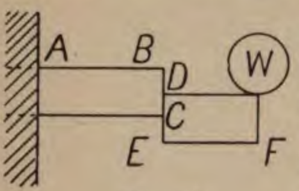


FIG. 100.

This second effect of the load is like that of the jaws of a shearing machine, so the tendency of the weight to produce vertical movement at any section is called the Shearing Force (S.F.) at that section.

To prevent this movement, the end $B\,C$ of $A\,C$ must exert forces or stresses on the end $D\,E$ of $D\,F$ sufficient to keep it in position. The amount of the stress is clearly equal to the vertical force W.

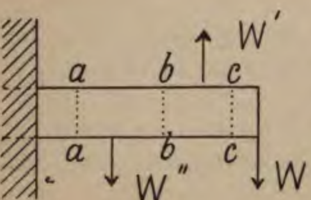


FIG. 101.

Taking Fig. 101, the Shearing Force at $c\ c$ is equal to W, but, proceeding to the section $b\ b$, this force is diminished by the upward force W', so the Shearing Force at $b\ b$ is $W-W'$. Proceeding again to the section $a\ a$ the Shearing Force is augmented by the downward force W'', therefore the S.F. at $a\ a$ is $W-W'+W''$.

Since, in Fig. 101, there are four parallel forces in equilibrium, the "reaction of the wall" is equal to $W - W' + W''$. Commencing on the left, the S.F. at $a\,a$ is equal to the reaction of the wall, i.e., $W - W' + W''$.

To the left of $b\,b$ the forces are the reaction of the wall and W'' acting in the opposite direction, therefore the S.F. at $b\,b$ is $(W - W' + W'') - W'' = W - W'$.

To the left of $c\,c$ the forces are the reaction of the wall, W'', acting downwards, and W', acting upwards, therefore the Shearing Force at $c\,c$ is $(W - W' + W'') - W'' + W' = W$.

These results correspond with those obtained for the various sections when considering the forces on the right of those sections.

Hence the S.F. at any section is obtained by finding the algebraical sum of all the forces on either side of the section.

184. By drawing ordinates from each point on the force diagram across the space represented on the beam by the same letter as that which distinguishes that point on the force diagram, a Shearing Force diagram can be obtained which will graphically represent the S.F. at every point of the beam.

An examination of Figs. 102, 103 and 104 will make this clear.

185. Ordinates across the Shearing Force diagram perpendicularly under any point of the beam, and measured on the force scale, will give the Shearing Force at that point of the beam.

For the S.F. at any part of the space A (Fig. 104) is given by $a\,b - b\,c + c\,d$ or $d\,a$; the S.F. at any part of the space B is given by $d\,a - a\,b$ or $b\,d$; and the S.F.

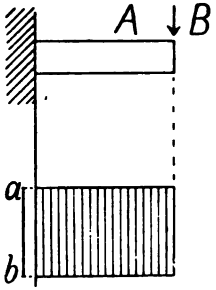


FIG. 102.

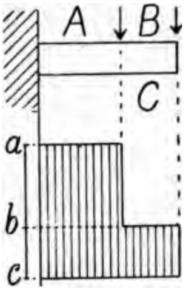


FIG. 103.

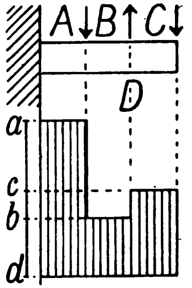


FIG. 104.

at any part of the space C is given by $d\,a - a\,b + b\,c$ or $c\,d$.

186. If a cantilever carries a uniformly distributed load, the S.F. at the unsupported end is nil, but it gradually increases as the wall is approached until at that end it is equal to the total load.

The S.F. diagram is therefore drawn as shown in Fig. 105.

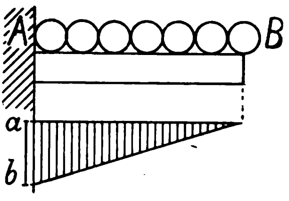


FIG. 105.

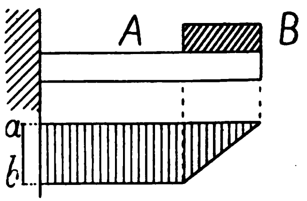


FIG. 106.

187. Fig. 106 shows a cantilever with a load distributed over a portion of its length. It will be noticed that the S.F. for the whole space A is equal to the total load, but that under the load it gradually diminishes towards the outer end.

188. If necessary the Shearing Force due to concen-

trated and uniformly distributed loads on a cantilever can easily be shown on one diagram.

Fig. 107 shows such a Shearing Force diagram where *c d* represents the uniformly distributed load.

189. The Shearing Force diagrams for beams supported at both ends are obtained in the same way as those for cantilevers, but as the S.F. is the algebraical sum of all the forces on either side of the section taken, and the reactions of the supports are forces acting on the beam, it will be necessary to find them. This has been done, as will be seen on referring to Figs. 108 and 109, by means of the funicular polygon.

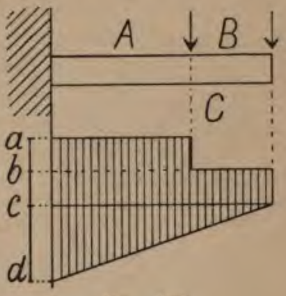


Fig. 107.

If the *polar distance* be known, then these funicular polygons also serve as Bending Moment diagrams (§ 171).

The Shearing Force diagrams are obtained, as previously explained, from the force diagram. An examination of the two shearing force diagrams should make this quite clear.

Figs. 108 and 109 show how to draw the B.M. and S.F. diagrams for an irregularly loaded beam in one figure.

190. If a beam carries a uniformly distributed load, the S.F. at each end is equal to the reactions of the supports, each of which is equal to one-half of the load. From each end it gradually diminishes as the centre of the beam is approached.

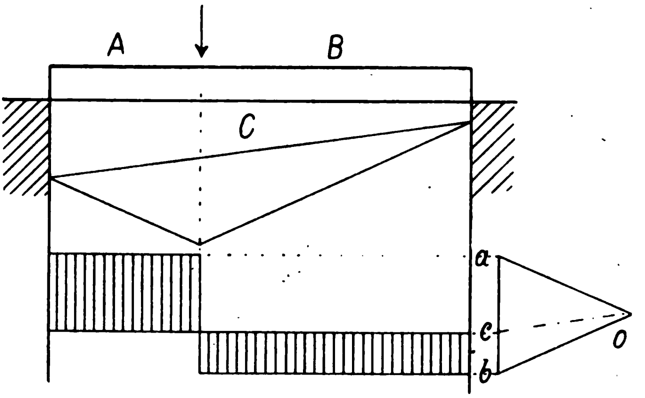


Fig. 108.

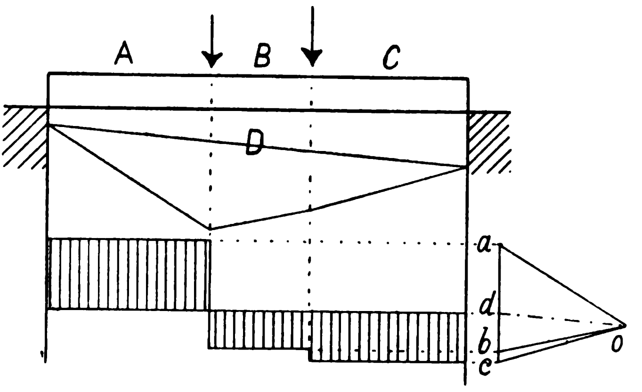


Fig. 109.

Figs. 110 and 111 show alternative ways of drawing the Shearing Force diagram under these circumstances.

191. In order to show on one diagram the S.F. due to the two systems of loading of a beam supported at both

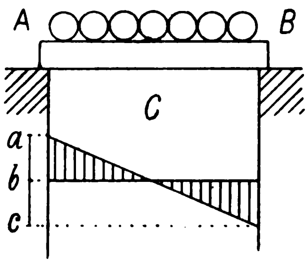


FIG. 110.

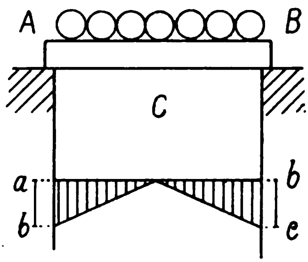


FIG. 111.

ends, it is necessary to modify the S.F. diagram of Fig. 109.

This modification, together with the diagram showing the Shearing Force of the uniformly distributed load, is shown in Fig. 112.

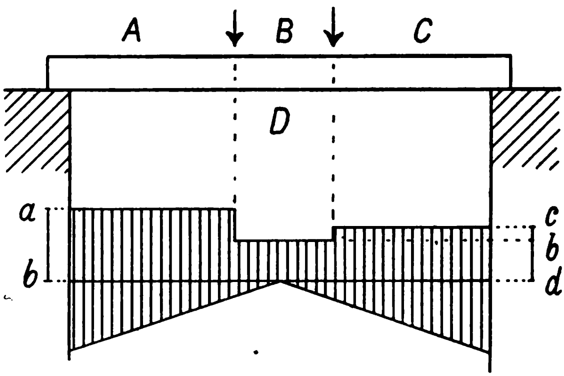


FIG. 112.

EXAMPLES TO CHAPTER VI

1. What does "the bending moment" mean ?
2. How is the B.M. scale found ?

In a certain exercise the lineal scale was $\frac{1}{96}$ and the "polar distance" 5 cwts.

Give the B.M. scale.

3. A beam, 15 ft. long and supported at both ends, carries a load of 2·5 tons 6 ft. from one end.

Find the greatest B.M. and the B.M. at the centre.

4. Draw the B.M. diagram for a beam 20 ft. long with a distributed load (including its own weight) of 15 tons.

5. A cantilever, 8 ft. long, supports a load of 5 cwts. at its outer extremity.

Find, geometrically, the moment about the centre.

6. What is meant by "the Shearing Force?"

7. A cantilever 10 ft. long has a distributed load of 3 cwts. per ft. on the outer half.

Draw the Shearing Force diagram, and give the S.F. at the wall end.

8. A beam, which is supported at both ends, and is 20 ft. long, has a load of 6 tons placed 6 ft. from one end.

Find the "bending moment" and the "shearing stress" at the centre of the beam.

9. A beam, fixed at one end and 11′ 6″ long, supports three loads—5 cwts. 3′ 10″ from the wall, 6 cwts. 7′ 8″ from the wall, and 2 cwts. at the unsupported end.

Find the B.M. and S.F. at the centre.

10. A girder 20 ft. long supports a load of 5 cwts. 6 ft. from one end and a load of 7 cwts. 4 ft. from the other.

What load could be placed at the centre of a similar beam, so that the maximum bending moment may be the same as that at the centre of the given beam?

Chapter VII

STRESS OR RECIPROCAL DIAGRAMS

192. It has been shown in Chapter IV that forces can be applied along certain directions to resist the action of some force or forces and so maintain equilibrium.

The usual method of introducing these new forces is by means of bars of iron or wood. The members thus introduced have to exert a certain amount of force, depending on the magnitude of the force or forces they have to resist, and on the angles at which they are applied (§ 97). The resistance thus brought forth from the bar is called "the stress," and by means of the triangle or polygon of forces its magnitude and direction can be obtained.

193. It was also shown in § 92 that a bar exerting a force at one end exerts an equal and opposite force at the other. Hence these new members are only introduced to transmit the force from one point to a more convenient one, either to the point of support, or to a point where other members can be introduced to further transmit it.

As an example of the former see Figs. 58 and 59, where, to support the weight, two members are introduced. These are secured to the wall, to which the force exerted by the weight is conveyed.

To illustrate the latter the cantilever shown in Fig. 113 will be examined.

If we only consider the force *A B* and the bars *B C* and *C A*, we have a repetition of Fig. 59, and the magnitude and direction of the stresses set up in *B C* and *C A* are given by the lines *b c* and *c a* in the triangle *a b c*. The bar *B C* is exerting a force towards the load, therefore it exerts an equal force towards the joint at the

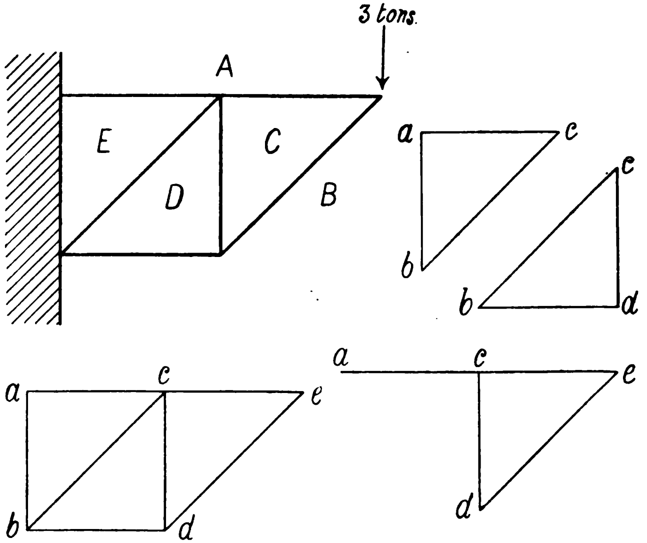


FIG. 113.

opposite end, and is in compression (§ 92). *C A* acts from the load, consequently it acts from the opposite joint, and is in tension.

We will now examine the joint at the lower end of *B C*. We have there three bars, *B D*, *D C*, and *C B*, but we have just determined the magnitude and direction of the force exerted by *C B*. It is represented by *c b*. By reproducing *c b*, and drawing lines parallel to *B D*

and $D\ C$ the triangle $c\ b\ d$ is obtained, and the lines $b\ d$ and $d\ c$ give the magnitude and direction of the stresses set up in $B\ D$ and $D\ C$. It will be seen that $B\ D$ is a compression bar and $D\ C$ a tension bar.

Proceeding to the opposite end of $D\ C$, we have four bars, $A\ C$, $C\ D$, $D\ E$ and $E\ A$. Two of these, $A\ C$ and $C\ D$, have already been determined, and, since they are tension bars, they act away from the joint. Draw $a\ c$ and $c\ d$ to represent these in magnitude and direction, remembering that the order in which the letters are placed must indicate the direction of the force represented by the line.

From a draw a line parallel to $E\ A$, and from d a line parallel to $D\ E$. Let these intersect at e. Then $d\ e$ and $e\ a$ will represent the stresses in the bars $D\ E$ and $E\ A$.

194. The student will no doubt have noticed that instead of reproducing $c\ b$, the triangle $c\ b\ d$ could have been made on the $c\ b$ of the first triangle, and that the figure thus obtained could have been utilized to form the last figure. The figure $a\ b\ d\ e\ c$ is formed by combining the three figures in this way, and, since the stress in each member of the cantilever can be obtained from it, it is called the "stress diagram."

The combination of the various force diagrams in this manner saves time and prevents mistakes arising through inaccurately transferring the measurements.

195. The magnitude of the stress in each bar is obtained by measuring with the force scale.

196. The stress diagram, being a force diagram, must close.

197. The loads and the reactions of the supports are called *the exterior or external forces*, and the stresses are called *the interior or internal forces.*

198. The method of procedure in drawing a stress diagram is almost the same in every case, and, if the student thoroughly understands one, he will have less difficulty in applying his knowledge to new problems. For this reason it is intended to more fully explain how the forces act in the cantilever shown in Fig. 113. The frame and stress diagrams of that figure are reproduced in Fig. 114, with the joints of the frame diagram numbered for reference.

199. It was explained in the chapter on Bow's notation, that, if the known force (or forces) acting at a point be named in clockwise order, and if the first letter of such name be placed first in the line of action of the line representing such force (or forces), then the letters naming the other forces will, when taken in the same direction round the figure, give the direction of the unknown forces.

It was also explained that compression bars exert an outward force (i.e. towards the joint) at each end, and the tension bars an inward force (i.e. from the joint) at each end.

If, then, it is necessary to find the kind of stress in a bar, all that is required is to select a joint at one of the ends of a bar, name it in clockwise order, and follow the direction of the corresponding letters on the stress diagram.

As an example, we will take the vertical bar (Fig. 114).

If we select the joint marked 2, this bar is $D\,C$. D is the first letter, so d on the line $d\,c$ of the stress diagram is the first point in its course of action, hence the force acts upwards from the joint 2. Proceeding to the joint 3, the bar, when named in clockwise order, becomes

C D. *C* is now the first letter, and, turning to the stress diagram, we find that from *c* to *d* is a downward direction. *C D*, therefore, acts from the joint 3. Hence the bar *C D* or *D C* is in tension. Since both ends of a bar exert the same kind of force (i.e. inwards or outwards) only one end need be examined. It should be noticed that, when considering one end of the bar, the stress was given by *c d*, and, when considering the other end, it was represented by *d c*.

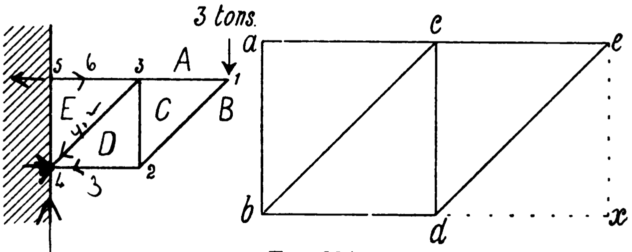


Fig. 114.

What has been said about the bar *C D* and its reciprocal line *c d*, applies to all the bars and their reciprocals.

200. Taking the joint marked 1, the forces are *A B*, *B C* and *C A*, and these are represented in magnitude and direction by *a b*, *b c*, and *c a*, that is, to maintain the load *A B*, the bar *C A* must exert a pull equal to 3 tons, and the bar *B C* must push with a force equal to 4·2 tons. In order that *C A* should exert a pull, the other end must be attached to something to which it transmits the force as shown by the string (§ 93). It is secured to the joint 3, and here it exerts a pull equal to 3 tons, as shown by *a c* on the stress diagram.

B C pushes against the load, and, by doing so, presses towards the joint 2 with a force, as shown by *c b*, equal to 4·2 tons. To resist this thrust the two bars *B D* and *D C* are introduced. The bar *B D*, as shown by *b d*, pushes towards the joint with a force equal to 3 tons, and by doing this exerts an equal pressure against the wall at the joint 4. The bar *D C* has to exert an upward pull at the joint 2, which, as we have already seen, means a downward pull at the joint 3. This pull is given by *c d* as being equal to 3 tons. This downward pull of *C D* is resisted by the action of the bars *D E* and *E A*. *D E* pushes towards the joint 3 with a force equal to 4·2 tons, and consequently exerts an equal pressure against the wall at the joint 4. The pull in *E A* caused by the action of *C D* and *D E* is shown by *e c* to be equal to 3 tons, but in addition to this, it has to resist the pull of *A C*, therefore the total tension in *E A* is equal to 6 tons, as shown by *e a* on the stress diagram, and this acts away from the joint 5.

201. Having ascertained the kind and amount of stress of each bar, we will now consider the effect on the wall.

We have seen that at the joint 5 there is an outward pull of 6 tons. At the joint 4, *B D* gives a direct thrust of 3 tons, and *E D* an oblique thrust of 4·2 tons. *E D* must be resolved into its vertical and horizontal components, each of which is equal to 3 tons, as shown by *e x* and *x d*. The total horizontal thrust at the joint 4 is therefore equal to 6 tons.

Hence the two horizontal reactions of the wall are each equal to 6 tons, but opposite in direction, and the vertical reaction of the wall is equal to 3 tons.

202. The same principle underlies the construction

of all framed structures, viz. the transference of a force from one point to another where it can be more conveniently dealt with, and, as the known forces can be utilized to discover the unknown ones, the stress in every part of a framed structure can be ascertained by means of the stress diagram.

203. The stress diagram is a valuable check on results arrived at arithmetically, and if a structure be badly designed, the stress diagram at once makes it apparent by exposing the redundant members, and refusing to close if necessary members are omitted.

204. Having determined the kind and amount of stress which the proposed load will produce in each member of a framed structure, the sectional area of the members can be determined.

205. It is now intended to find the stresses produced by given loads in the members of the more common structures. After what has been said about the action of forces, and the explanation of the stress diagram in this chapter, the student will have no difficulty in following them.

The method of procedure is as follows :—

(1) Set out the structure to scale.

(2) Adopt a force scale and draw the line of loads.

(3) Determine the position of the loads, and indicate them on the structure. The loads are to come on the joints of the structure. If the true position of a load be at some intermediate point of a bar, it must be so divided that each joint at the end of the bar gets its proper proportion of the load.

(4) Determine the reactions of the supports. If the structure be symmetrical and symmetrically loaded, each reaction will be equal to half the load ; if not, the

reactions may be determined by means of the funicular polygon.

(5) Place letters (or numbers) between all the exterior forces, and then in all the spaces of the frame.

(6) An exterior force (usually one of the reactions, though not always), is now chosen where not more than two members act, and resolved along their directions.

(7) At the next joint one of these is combined with the exterior force (if there be one), and resolved along the direction of the other bars. This process is continued until all the bars are resolved.

206. Fig. 115 shows a span roof with a load concentrated at the ridge.

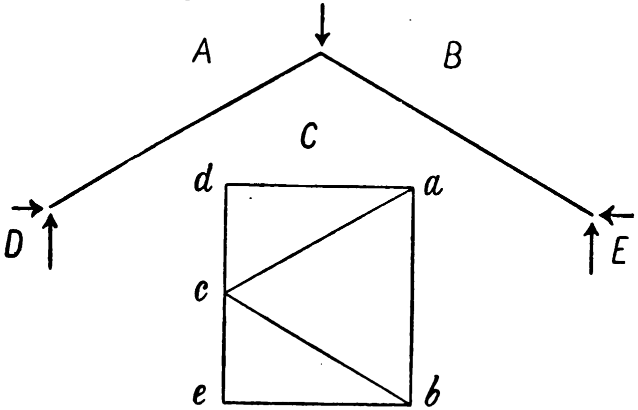


FIG. 115.

At the ridge there are three forces, the load $A\ B$ and the two rafters resisting this. Since there are three forces in equilibrium, and $A\ B$ is known, the triangle of forces can be applied to determine the others. $a\ b\ c$ is this triangle, and, as the names of the rafters in clockwise order are $B\ C$ and $C\ A$, $b\ c$ and $c\ a$ give the directions

as well as the magnitudes of the forces exerted by them. These act towards the joint, and are therefore in compression. Taking the rafter $C\,A$, since it exerts a pressure represented by $c\,a$ at the ridge, $a\,c$ will represent the pressure it exerts at the foot. This force is resisted by the vertical and horizontal reactions of the wall $C\,D$, and by resolving the force $a\,c$ along those directions the triangle $a\,c\,d$ is obtained. $c\,d$ and $d\,a$ represent those reactions, therefore $d\,c$ shows the proportion of the load $A\,B$ borne by the wall $C\,D$, and $a\,d$ represents the force which tends to overturn the wall.

The rafter $B\,C$ presses with a force represented by $b\,c$ towards the ridge, and consequently with a force $c\,b$ towards the foot. This, being resolved in vertical and horizontal directions, gives $c\,e$ the vertical thrust and $e\,b$ the horizontal thrust of the rafter.

It should be noticed that the two vertical reactions of the walls are together equal to the total load. This is shown by $e\,c$ and $c\,d$ (or $e\,d$) being equal to $a\,b$.

The two horizontal reactions are also equal, as shown by $d\,a$ and $b\,e$.

207. If one of the rafters be more inclined than the other, as in Fig. 116, we find that the stress in this is greater than in the less inclined one, and that this in turn produces a greater vertical reaction.

This is what we should expect, because the line of action of the load $A\,B$ is nearer to $E\,C$ than to $C\,D$.

Again, the sum of the two vertical reactions is equal to the load, and the horizontal reactions are equal to each other.

208. With six spring balances, a few pieces of string, and a weight, fitted up as shown in Fig. 117, the student may perform a very interesting experiment for himself.

The only difference between this and the two previous examples is that the directions of the forces are reversed, but this will not affect their magnitudes.

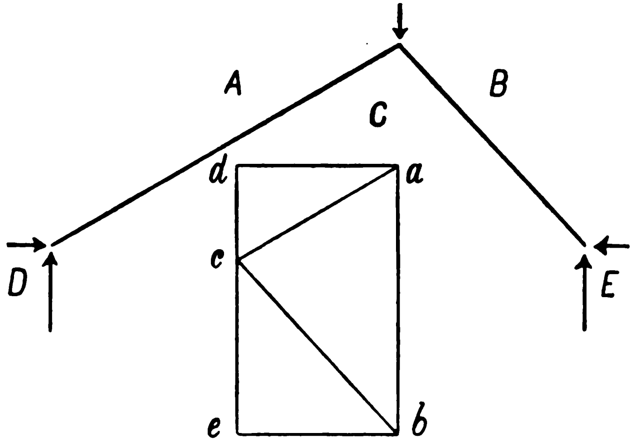


FIG. 116.

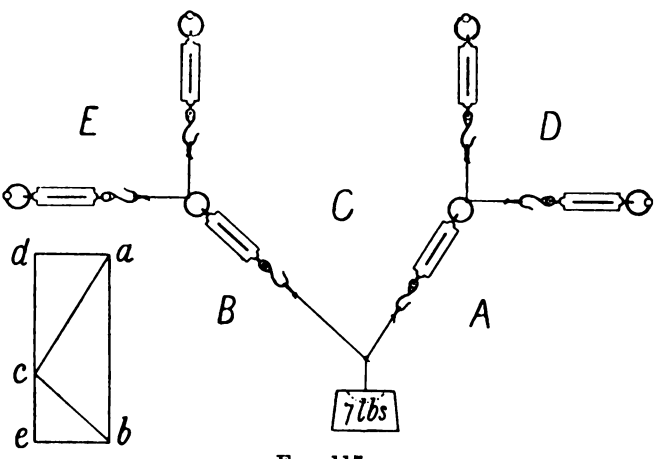


FIG. 117.

The weight can be slipped to different positions, and the effect on each balance noted.

Briefly, they are as follows :—

(*a*) The more inclined any section of the string becomes, the greater is the stress produced.

(*b*) The nearer the weight is to one side, the greater is the proportion of the weight supported by the vertical balance on that side.

(*c*) The two vertical balances together always register a force equal to that of the weight.

(*d*) And the forces registered by the horizontal balances are always equal to one another and opposite in direction.

As an exercise he should select one of the positions, graphically determine the forces, and compare the results with those shown on the balances.

209. In the two previous exercises we have assumed that the total load is on the ridge. Each rafter is in reality a beam with a distributed load, and half this load is supported at each end. Thus the load on the ridge is only one half the total load, the other half being supported directly by the walls. Fig. 118 shows the load apportioned in this manner. A new member is also introduced.

Draw $a\,b$, $b\,c$ and $c\,d$ to represent the three loads. $a\,d$ now represents the total load, and $d\,a$ the total reactions. The frame and the loading being symmetrical the two reactions will be equal. Bisect $d\,a$. The reactions of $D\,E$ and $E\,A$ are represented by $d\,e$ and $e\,a$ respectively. Since $e\,a$ represents the total reaction of the wall $E\,A$, and the load represented by $a\,b$ is supported directly by the wall, the remainder $e\,b$ is the reaction caused by the load on the frame.

By resolving *e b* in directions parallel to *B F* and *F E* the triangle *e b f* is obtained. The sides of this represent the forces in magnitude and direction when taken in order round the triangle. If we follow them we find that *B F* is in compression and *F E* in tension.

We can proceed in a similar manner with the other reaction, and obtain the triangle *c e f*, which determines the forces exerted by *E F* and *F C*. It should be noticed

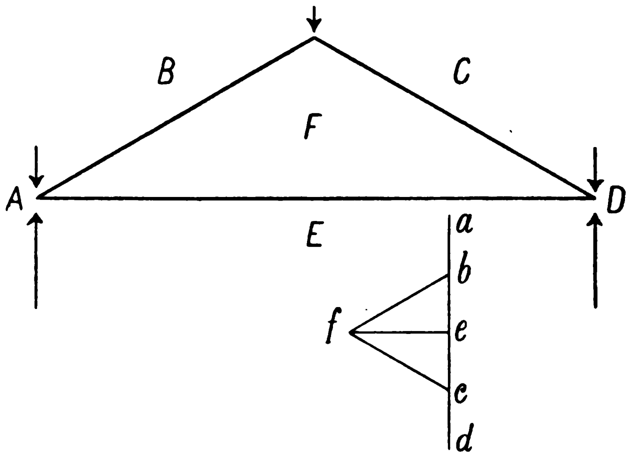


FIG. 118.

that the new member is introduced to resist the outward thrust of the rafter, which it does by exerting an inward force at each end.

(We may, if we like, treat the foot of the rafter as if the four forces, *E A*, *A B*, *B F* and *F E* were acting. *E A* and *A C* are known, and by resolving them along the directions of the others, we get a polygon of forces whose sides are *e a*, *a b*, *b f* and *f e*. But *a b* lies on a

portion of $e\,a$, and the polygon appears as shown by $e\,a\,b\,f\,e$.)

210. We will now take a roof, as shown in Fig. 119, and

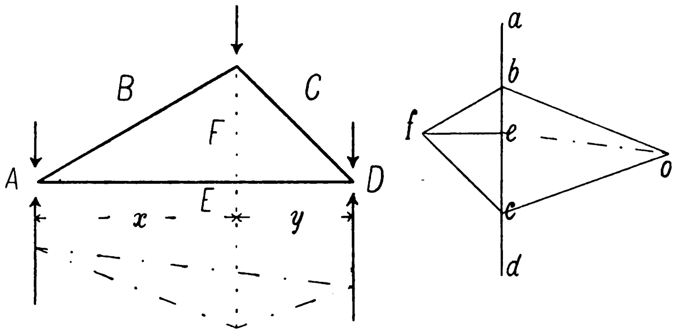


FIG. 119.

suppose the load on each rafter to be 6 cwts. Apportioning the load, we get 6 cwts. on the ridge and 3 cwts. on each wall.

Since the line of action of $B\,C$ is nearer the one wall than the other, they will not support equal shares, so we must fall back on one of the methods of determining the reactions.

The usual way is by means of the funicular polygon. Draw the line of loads. Since it is the proportion of $B\,C$ which each wall supports that has to be determined, join b and c to a pole. Draw the funicular polygon and $o\,e$ parallel to the closing link. $d\,e$ and $e\,a$ now represent the total reactions of $D\,E$ and $E\,A$ respectively. ($c\,e$ and $e\,b$ could have been found by means of similar triangles (§ 51), or, if x and y be known, they could have been ascertained by taking the moments about either support (§ 50).)

Having ascertained the position of e, the stress diagram can be drawn as in the previous exercise.

211. Taking Fig. 118, and adding a vertical member (a king-rod) we obtain Fig. 120.

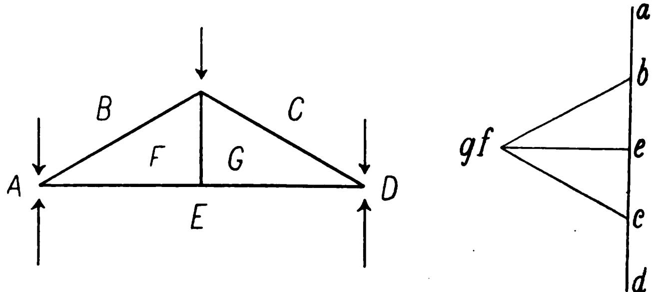


Fig. 120.

The stress diagram shows f and g at the same point. The distance between them being *nil*, shows that the load produces no stress in $F\,G$.

This is what we should expect, since at the bottom of $F\,G$ there are three bars, two of which are parallel, meeting at a point (§ 110).

212. If we camber the tie-rod, we obtain Fig. 121.

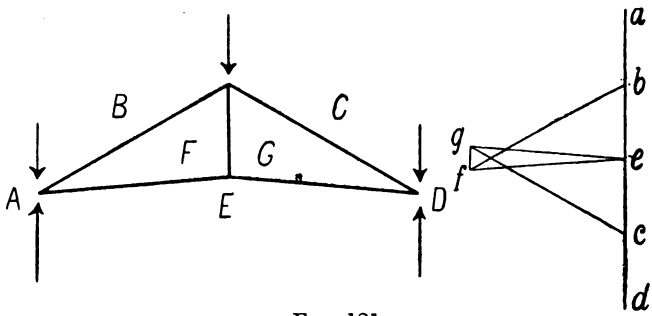


Fig. 121.

Resolve $e\,b$, the resultant of $E\,A$ and $A\,B$, in directions parallel to $B\,F$ and $F\,E$, thus obtaining $b\,f$ and $f\,e$. $b\,f$ represents the force exerted by $B\,F$ at the foot, therefore $f\,b$ represents the force it exerts at the ridge. At this latter point there are four forces, but $F\,B$ and $B\,C$ are known, and are represented by $f\,b$ and $b\,c$, therefore by drawing lines from c and f parallel to $C\,G$ and $G\,F$, $c\,g$ and $g\,f$ are obtained, and these give the stresses in those members. By combining the force $g\,c$ with $c\,e$, the resultant of $C\,D$ and $D\,E$, and resolving parallel to $E\,G$, $e\,g$ is obtained, and this gives the tension in $E\,G$.

It will be seen that by cambering the tie-rod, a tensile stress is produced in the king-rod.

213. Fig. 122 shows another kind of roof truss. It is formed by the addition of two members to Fig. 120.

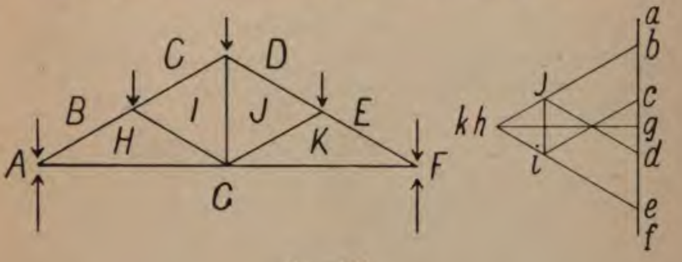


FIG. 122.

Resolve $g\,b$ as before, and so obtain $b\,h$ and $h\,g$. Combine $h\,b$ with the load $b\,c$, and resolve parallel to $C\,I$ and $I\,H$, thus obtaining $c\,i$ and $i\,h$. By combining $i\,c$ and $c\,d$, and resolving parallel to $D\,J$ and $J\,I$, $d\,j$ and $j\,i$ are determined, and by combining $j\,d$ with $d\,e$ and drawing lines parallel to $E\,K$ and $K\,J$, $e\,k$ and $k\,j$ are obtained. Since k and h are at the same point, $g\,k$ is equal to $h\,g$, therefore the stresses in all the members are found.

The lines *h i* and *k j* coincide with a portion of the lines *h e* and *k b* respectively, but this should present no difficulty, if it be remembered that each is a side of a polygon of forces.

214. By cambering the tie-rod of the last figure we obtain Fig. 123.

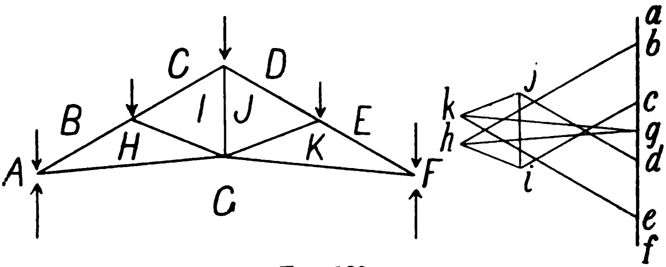


FIG. 123.

h and *k* do not now come together, neither do *h i* and *k j* coincide with *h e* and *k b* as in the last exercise.

215. In Fig. 124 we have a different arrangement.

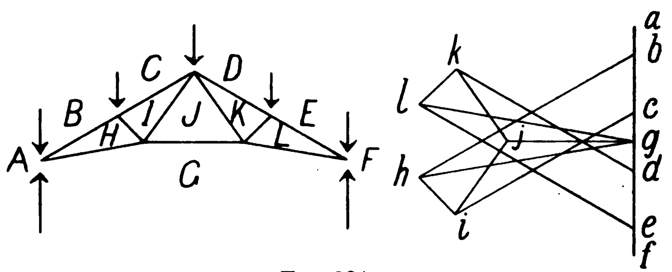


FIG. 124.

By means of the reactions, *B H* and *H G* can be determined. The stress in *H B* and the load *C D* can be utilized to obtain the stresses in *C I* and *I H*. If we proceed to the ridge, we find that of the five forces acting

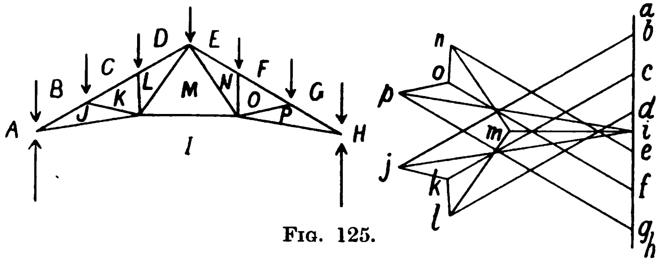


FIG. 125.

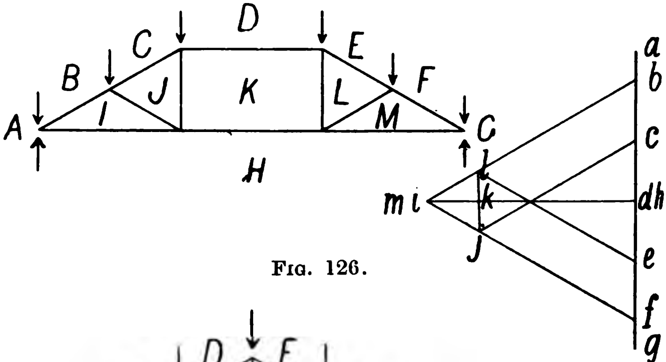


FIG. 126.

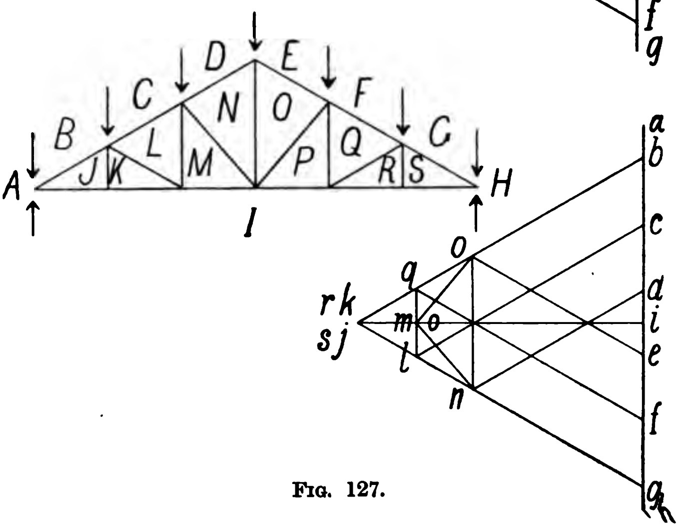


FIG. 127.

there, we only know $I\ G$ and $C\ D$, so we cannot proceed at that point. If we go to the joint at the bottom of $H\ I$, by means of the stresses of $G\ H$ and $H\ I$, we can find those of $I\ J$ and $J\ G$. Now we know three of the five forces acting at the ridge, so that we can determine the others. This problem presents no further difficulty.

216. Figs. 125, 126, and 127 show trusses which are loaded at a greater number of points.

The construction of the stress diagrams for these should present no difficulty, if it be remembered that the line representing the stress in one bar may lie partly or wholly on the line representing the stress in another bar.

The bars $J\ K$ and $R\ S$ (Fig. 127) may at first prove a little disconcerting, but an examination of them will show that at the bottom joint of each there are three bars, two of which are parallel, therefore the stress in $J\ K$ and $R\ S$ due to the loading is *nil* (§ 110). They are introduced to prevent the tie-rod sagging.

217. Fig. 128 shows a braced cantilever with a concentrated load at its outer end.

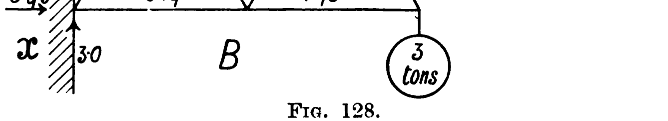


FIG. 128.

The stresses in $B\ C$ and $C\ A$ are obtained by resolving $A\ B$ along those directions and so obtaining the triangle

a b c. *c a* represents the force exerted by *A C* at its lower end, therefore *a c* is that which it exerts at the upper end. By resolving this parallel to *C D* and *D A*, we get *c d* and *d a*, which give the stresses in those members. By combining the stresses of *D C* and *C B* and resolving parallel to *B E* and *E D*, a polygon whose sides are *d c*, *c b*, *b e*, and *e d*, is obtained. *b e* and *e d* give the stresses in *B E* and *E D* respectively. Similarly by combining the stresses of *A D* and *D E*, those of *E F* and *F A* are obtained.

The reactions of the wall are determined as shown in § 201.

218. Fig. 129 shows a braced cantilever with a distributed load.

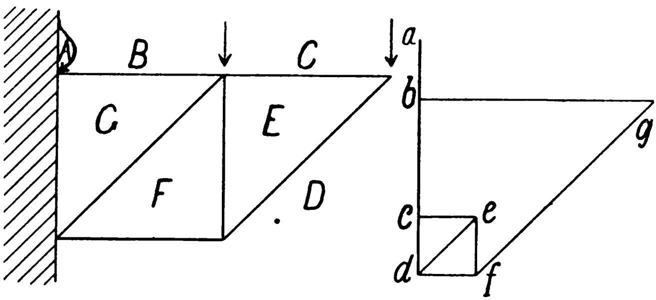


FIG. 129.

The first thing we have to consider is how to divide the load. It will be seen that it is supported by two bars of equal length. Each supports one half of the total load, therefore one quarter of the total load is supported at each end of the two bars.

Thus *A B* equals one quarter of the load, *B C* equals one half of the load, and *C D* equals one quarter of the load.

By means of the load $C\,D$ the stresses of $D\,E$ and $E\,C$ are obtained. The stress of $E\,D$ is utilized to find those of $D\,F$ and $F\,E$. By combining the load $B\,C$ with the stresses of $C\,E$ and $E\,F$, the stresses of $F\,G$ and $G\,B$ are determined.

219. Fig. 130 shows another form of braced cantilever with a distributed load.

In allocating the load to its various points of support, we find that the bar $B\,G$ is one half the length of the bar $C\,E$, and consequently receives only one third of the load. Half of this third, or one sixth of the total load, is supported at each end of the bar $B\,G$. Half

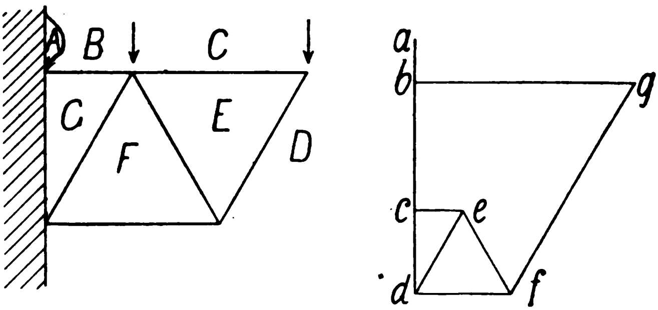


FIG. 130.

of the remainder, or one third of the total load, is supported at each end of $C\,E$. The total load, then, is so divided that $A\,B$ equals one sixth of the load, $B\,C$ equals $\frac{1}{6} + \frac{1}{3}$ or $\frac{1}{2}$ of the load, and $C\,D$ equals $\frac{1}{3}$ of the load.

The stress diagram is drawn in exactly the same manner as that of the last exercise.

220. When dealing with the roof trusses, we obtained the magnitude of the stress in each bar by measuring with the force scale its corresponding line on the stress diagram.

Looking at the stress diagrams of Figs. 128 and 129, we see that the former is made up of equilateral triangles and half such triangles, and that the latter is made up of right-angled isosceles triangles. As the sides of these triangles always bear a certain relationship to each other, if we know the length of one side we can easily obtain that of the others.

We will first examine the stress diagram of Fig. 128. If we know the lengths of the sides of the triangle $a\,b\,c$, we know the lengths of all the other lines in the diagram. The relationship between the sides of this triangle is as follows :—

$$b\,c = \cdot577 \times a\,b \text{ or } \tfrac{1}{2}\,a\,c,$$
$$a\,b = \cdot866 \times a\,c,$$
$$\text{and } a\,c = 1\cdot155 \times a\,b \text{ or } 2\,b\,c.$$

Proceeding to the stress diagram of Fig. 129, and taking the triangle $c\,d\,e$, we have—

$$c\,d = c\,e = \cdot707 \times d\,e,$$
$$\text{and } d\,e = 1\cdot414 \times c\,d.$$

To show how this knowledge is applied, a load of 3 tons is taken in Fig. 128. $a\,b$ now represents 3 tons, therefore $a\,c = 1\cdot155 \times a\,b = 3\cdot46$ tons, and $b\,c = 1\cdot73$ tons.

$a\,d$, $c\,d$, $d\,e$ and $e\,f$ are each $= a\,c = 3\cdot46$ tons.

$a\,f = 2\,a\,c = 6\cdot93$ tons.

$b\,e = b\,c \times c\,e = (1\cdot73 + 3\cdot46)$ tons $= 5\cdot19$ tons.

In this manner the stress in the bars of the foregoing cantilevers and the following girders can be obtained with mathematical accuracy without making use of the force scale. The magnitude and kind of stress in each bar should be indicated on the frame diagram as shown in Fig. 128.

221. The remaining figures show a few short Warren

and N girders under different kinds of loads, with their respective stress diagrams.

The difficulty which will be found in drawing the stress diagrams for these is caused by some of the bars not being called upon to resist the action of the load, i.e. the stress in them due to the load $= 0$.

Having ascertained these and determined the exterior forces, the drawing of the stress diagrams becomes comparatively easy.

Fig. 131. The load $A\,B$ being midway between the supports, the two reactions $B\,C$ and $C\,A$ are equal.

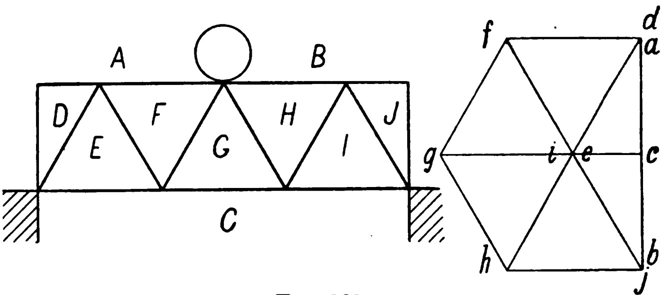


FIG. 131.

At each end of the top flange there are only two bars, and these are at right angles to each other. It is evident two forces acting at right angles to each other cannot maintain equilibrium, therefore, since these corners are in equilibrium, we know that these bars exert no force.

To indicate that the stress in $A\,D = 0$, d must be placed at the same point as a on the stress diagram. Similarly, j must be placed at the same point as b.

The stress diagram can now be drawn in the ordinary way.

222. Fig. 132 is the same girder as the last, with a distributed load on the top flange.

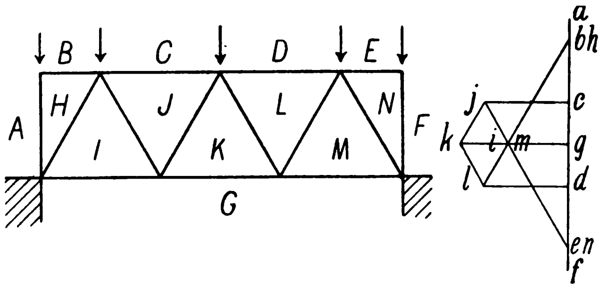


FIG. 132.

The chief difficulty in this is in apportioning the load to the several points of support.

The bars $B\,H$ and $E\,N$ being half as long at the bars $C\,J$ and $D\,L$, only receive half as much of the load, so $\frac{1}{6}$ of the load comes on each of the two former, and $\frac{1}{3}$ on each of the two latter. Half of each of these loads is supported at each end of the bars, therefore $A\,B = \frac{1}{12}$, $B\,C = \frac{1}{12} + \frac{1}{6}$ or $\frac{1}{4}$, $C\,D = \frac{1}{6} + \frac{1}{6}$ or $\frac{1}{3}$, $D\,E = \frac{1}{6} + \frac{1}{12}$ or $\frac{1}{4}$, and $E\,F = \frac{1}{12}$.

At either end of the top flange there are apparently three forces, two of which are parallel, hence we know that the stresses in $A\,H$ and $N\,F$ are equal to $A\,B$ and $E\,F$ respectively, and that the stresses in $B\,H$ and $E\,N = 0$ (§ 110).

To indicate this on the stress diagram, place *h* at the same point as *b*, and *n* at the same point as *e*.

Of course, the bars $B\,H$ and $E\,N$ are necessary to support the distributed load. They are subject to a cross strain which an ordinary stress diagram is unable to take account of.

223. Fig. 133 shows a distributed load on the bottom flange of a girder.

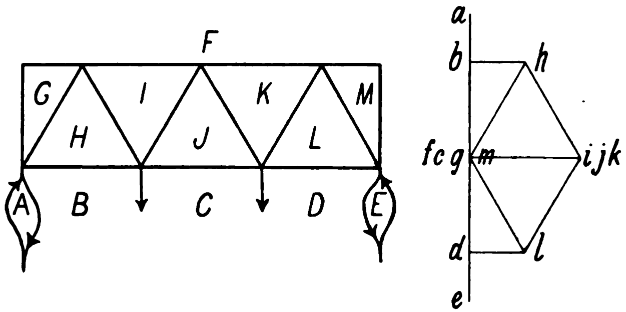


FIG. 133.

Here the load is distributed over three beams of equal length. Each receives $\frac{1}{3}$ the load, and transmits $\frac{1}{6}$ of the total load to each end. The two middle joints, therefore, receive twice as much as the outer ones.

Another difficulty presents itself—the two outer loads are in line with the reactions. How can these be indicated on the frame diagram? The plan usually adopted is to open out the line as shown, and place a letter in the space. The two outer lines must represent the reactions.

The point f coincides with the point c. At the ends of the top flange there is a repetition of what was found in Fig. 131, therefore g and m must be placed at the point f.

It will be seen that the letters i, j, and k are at the same point. This indicates that the stress in both $I\,J$ and $J\,K = 0$.

224. Fig. 134: The load is shown in the middle of a bar. To draw the stress diagram this load must be divided between the two joints at the end of the bar.

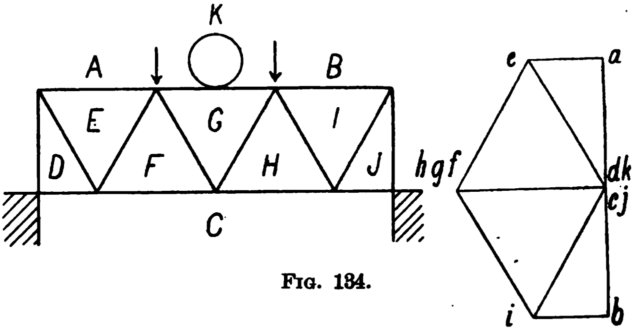


FIG. 134.

At each end of the bottom flange we have the reaction and two bars, but in each case two of these are parallel. We therefore know that the stresses in $D\,C$ and $C\,J = 0$, and those of $A\,D$ and $J\,B =$ the reactions (§ 110).

This is shown on the stress diagram by placing d and j at the point c.

The load does not affect $F\,G$ and $G\,H$.

225. Fig. 135 illustrates an N girder with a distributed load on the top flange.

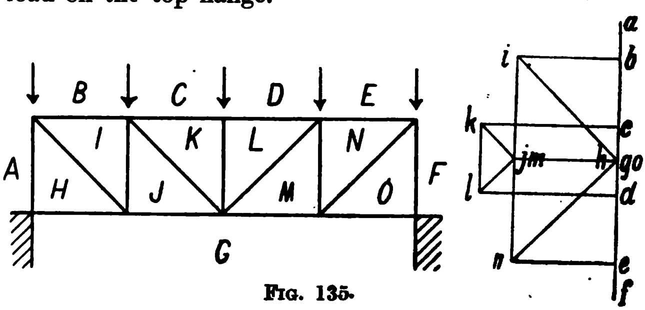


FIG. 135.

An examination of the bars $H\ G$ and $O\ G$ will show that the stress in each of them $= 0$.

By placing h and o at the point g, we have $h\ a$ and $f\ o$ equal to the reactions, and these represent the stresses of $H\ A$ and $F\ O$.

226. In Fig. 136 we have, as in Figs. 131 and 133, at each top corner, two theoretically useless bars. To

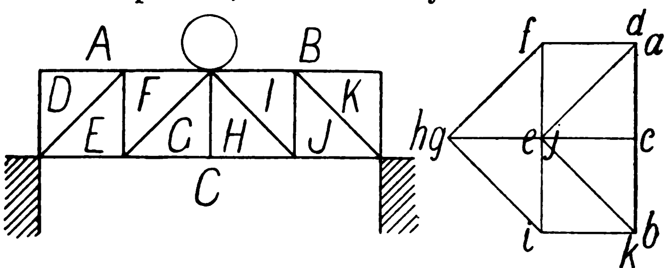


FIG. 136.

indicate their values on the stress diagram d must be placed at the point a, and k at the point b.

$G\ H$ is another bar which exerts no force, as can easily be seen by examining the bottom joint. Its work is to prevent sagging in $G\ C$ and $H\ C$.

227. In Fig. 137 the reactions are not equal. They

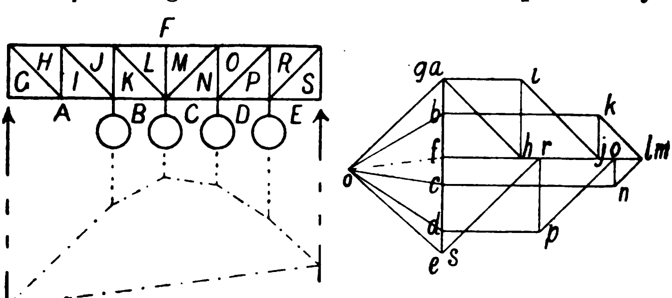


FIG. 137.

have been determined by means of the funicular polygon, and, of course, if the polar distance be known, the bending moment at any point can be obtained.

The stress in the bars $G\,A$, $S\,E$ and $L\,M = 0$.

The two former make the girder more rigid, and $L\,M$ strengthens the top flange by resisting any bending that is likely to occur in $F\,L$ and $F\,M$ through being in compression.

228. In Fig. 138 we have a lattice girder supporting a number of loads. In this a new difficulty presents itself, because at no point are there less than three unknown forces. In order to overcome this difficulty, we may consider the girder as being made up of the two girders shown in Fig. 138. The loads retain the same positions as on the original girder.

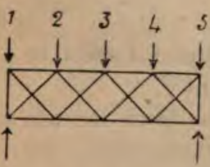


FIG. 138.

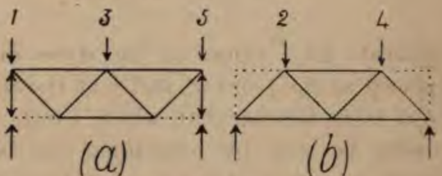


FIG. 139.

On examining Fig 139 (a) it will readily be seen that the compression of each of the vertical bars is equal to the reaction of the wall that supports it. These reactions are due to the three loads 1, 3 and 5, and can easily be determined whatever the loads may be. Turning to Fig. 139 (b) we see that the two loads 2 and 4 do not in any way affect the vertical bars referred to. Therefore, to ascertain the stresses of the two verticals or pillars, it is only necessary to find the reactions due to the loads 1, 3 and 5.

Having found the force exerted by each pillar, we have only two unknown forces at the points of support of the girder, and can proceed with the solution.

229. Fig. 140 shows the stress diagram for a lattice girder supporting a uniformly distributed load.

From the preceding paragraph it will be seen that, since the load is uniformly distributed, the stresses of *B H* and *T G* are equal to one another, each being equal to one quarter of the load. These are shown by *b h* and *t g* on the stress diagram.

230. By adding vertical bars to Fig. 140 we obtain Fig. 141. This is termed *a lattice girder with verticals.*

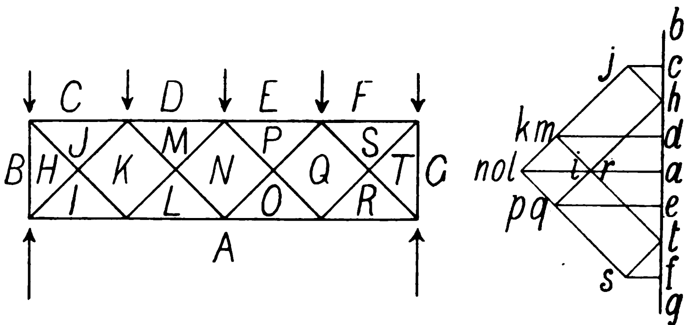


FIG. 140.

We may imagine this girder as being a combination of the two single girders (*a*) and (*b*) (Fig. 142).

The load on the original girder has now to be divided between (*a*) and (*b*) (Fig. 142). There is on each of these a point of support corresponding to every point of support on the combined girder, therefore half of each load on the original girder must be placed on the corresponding points of the single girders.

This is plainly shown in Figs. 141 and 142.

Having divided the combined girder into two single ones and apportioned the loads as described, the stresses in the bars of the former may be obtained by finding those in the bars of the single ones and combining them.

In considering Fig. 141 as being made up of (*a*) and (*b*) Fig. 142, it should be noted that the two booms and all the verticals are duplicated. Where members are duplicated, the stresses must be added or subtracted according as they are alike or unlike. When added, the sum will represent a stress of the same kind as those added, and when subtracted, the difference

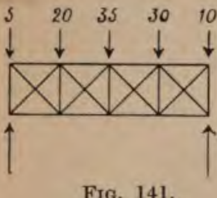


FIG. 141.

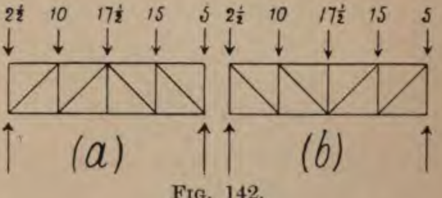


FIG. 142.

will represent a stress of the same kind as that of the greater.

In order to more clearly explain the method of procedure, the stress diagrams of (*a*) and (*b*) (Fig. 142) are drawn, and the values indicated on the girders (Figs. 143 and 144).

These results must now be combined and figured on the original girder, as already explained (see Fig. 145). Thus, the stress of the vertical BH (Fig. 143) is $+ 2{\cdot}5$ and that of BI (Fig. 144), which coincides with it when superposed, is $+ 22{\cdot}5$. Being stresses of the same kind, they must be added. The sum is $+ 25$, which gives the total stress of BI (Fig. 145). Taking the

vertical $I\,J$ (Fig. 143), the stress is -10, while that of the corresponding vertical $H\,K$ (Fig. 143) is $+20$. These, being unlike, must be subtracted and the difference given the sign of the greater. Therefore, the

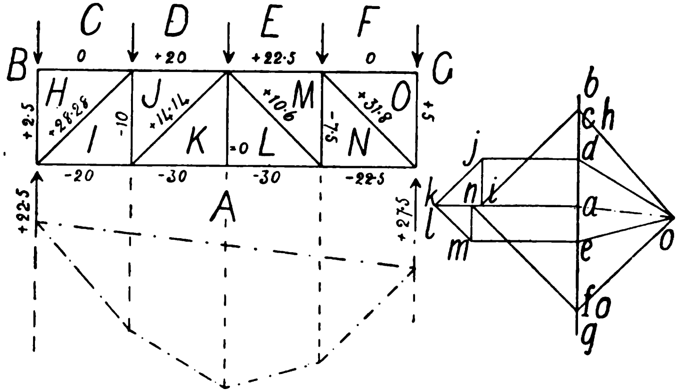


FIG. 143.

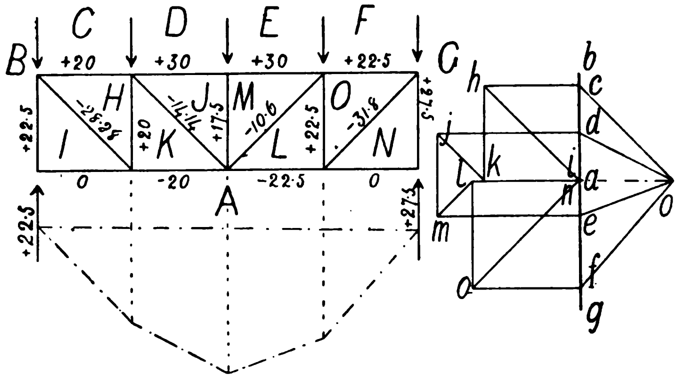


FIG. 144.

stress of $K\,L$ (Fig. 145) is $+10$. Again, $K\,A$ (Fig. 143) coincides with $K\,A$ (Fig. 144). The stresses of these

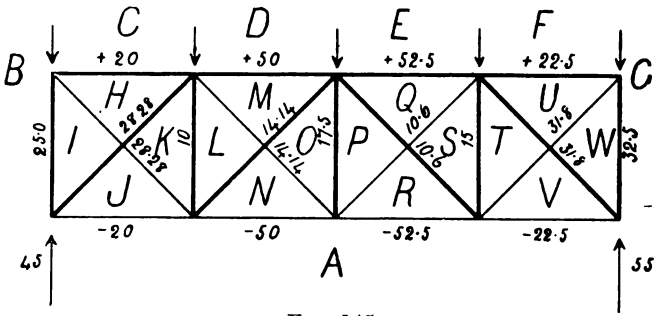


FIG. 145.

are -30 and -20 respectively, therefore the stress of $A\ N$ (Fig. 145) is -50. Proceeding in this manner, the stresses of all the members can be obtained. None of the diagonals are duplicated, therefore the stresses of these remain as found in Figs. 143 and 144.

231. Fig. 146 shows the same girder as that given in

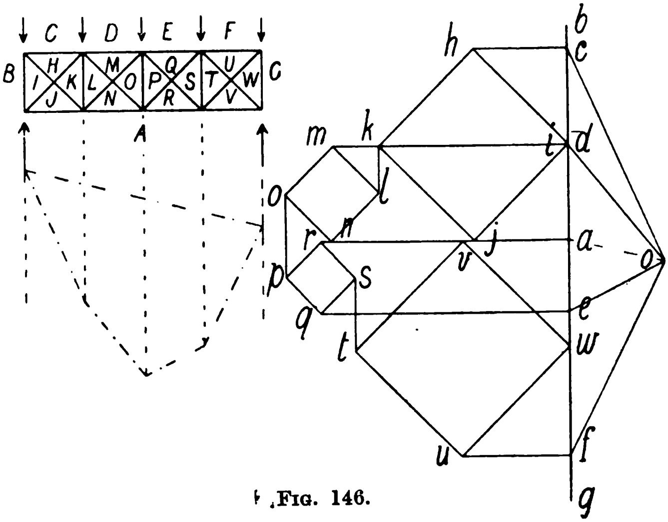


FIG. 146.

the last paragraph, but in this case all the stresses are obtained by means of one diagram. The loads are equal to those of the last exercise.

The first difficulty met with is that at the points of support there are four forces, only one of which is known. In order to find the stresses of $B\,I$ and $W\,G$ we must suppose the girder and loads divided as shown in Fig. 144, and find the reactions of the supports. The stresses in $B\,I$ and $W\,G$ due to this half of the load are respectively equal to these reactions, but to find the total compression in them, we must add to each the other half of the load which comes directly upon it. The compressive stress of $B\,I$ due to the half of the total load is 22·5, and half the load which comes directly upon it is 2·5, therefore the total stress in $B\,I$ is + 25. Similarly, $W\,G$ equals + 32·5.

The verticals $K\,L$, $O\,P$, and $S\,T$ will next prove troublesome, but the rule is to assume that the stress in each of these is equal to one half of the load bearing directly upon it, which agrees with the results obtained in the last exercise.

The exercise presents no further difficulty.

If the student remembers how to find the stresses of the outside verticals, and the rule relating to the inner ones, he should be able to find the stresses in a lattice girder with verticals under any system of loading.

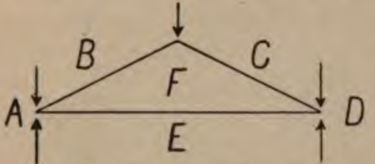
232. In actual practice the framed structures usually consist of a much greater number of parts, so that the alphabet is insufficient to name them all. The principle of Bow's Notation is retained, but numerals are used instead of letters. They have not the advantage of capitals and small letters respectively for the frame

and force diagrams, but there is no difficulty in using them when once the principle is fully understood.

233. In conclusion, it must not be supposed that complex structures can now be readily analyzed. There are some which may take years of study to elucidate, and others in which the result depends upon the nature of the workmanship, which cannot be foreseen. Students who have carefully worked through the preceding pages should be able to prepare stress diagrams for all ordinary cases, and, if they are ambitious, may try their hands at a collar-beam truss where the walls are not rigid, a hammer-beam truss, an arched roof truss, etc.

Examples to Chapter VII

1. Fig. 1 shows a couple close roof with a rise one quarter the span, carrying a distributed load of 16 cwts.



Ex. Ch. VII.—Fig. 1.

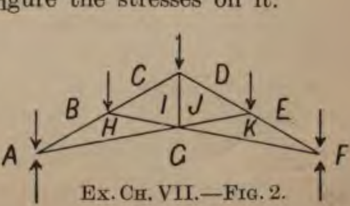
What are the stresses produced in each member ?

2. The roof truss given in Fig. 122 supports a distributed load of 5 tons.

Draw the truss and figure the stresses on it.

3. Fig. 2 shows a roof truss carrying a load of 4 tons. Pitch 30°.

Give the stresses of all the members.

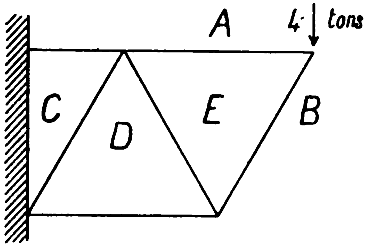


Ex. Ch. VII.—Fig. 2.

4. Taking the load on the Queen-post truss shown in Fig. 126 as 5 tons, determine the various stresses.

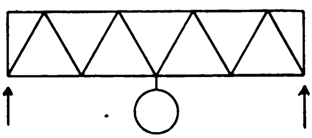
5. Find the amount and kind of stress produced in each member shown in Fig. 128, with a load of 2·5 tons at its extremity.

6. Find the stresses in each member, and the reactions of the wall, due to the load given in Fig. 3.



Ex. Ch. VII.—Fig. 3.

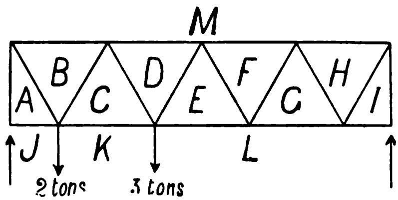
7. Fig. 4 is an elevation of a trussed girder with a concentrated load.



Ex. Ch. VII.—Fig. 4.

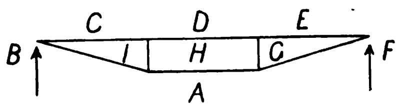
Draw to twice the scale, showing the members in compression by double lines, and those in tension by single lines, omitting any bars not affected by the load.

8. Determine graphically to a scale of $\frac{3}{4}''$ to a ton the reactions at the points of support, and the stresses set up in the different members of the loaded girder shown in Fig. 5.



Ex. Ch. VII.—Fig. 5.

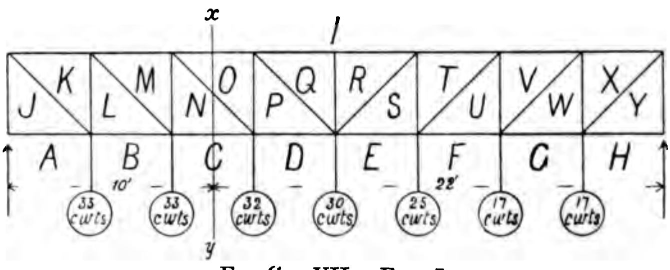
9. A girder 21 ft. long and 2 ft. deep is trussed as shown in Fig. 6.



Ex. Ch. VII.—Fig. 6.

Determine the stresses when it carries a distributed load of 1 cwt. per foot.

10. Draw the stress diagram of Fig. 7; mark on the



Ex. Ch. VII.—Fig. 7

truss the amounts of the stresses in cwts., distinguishing between compression and tension bars.

What is the bending moment at $x\,y$?

ANSWERS TO EXAMPLES

Examples to Chapter I (pp. 20, 21)

1. (*a*) 9·4 units; (*b*) 6·26 yards; (*c*) 3·13 tons; (*d*) 5371 lbs.
2. (*a*) 50·91 ft.; (*b*) 12·99 inches; (*c*) 22·79 ft; (*d*) Tiebeam, 25′·0; Principal, 14·43 ft.; King-post, 7·21 ft.; Struts, 7·21 ft.
3. 1·11 inches.
4. 4·05 units.
5. 1·809 units.
6. 4·53 units.

Examples to Chapter II (pp. 42, 43)

1. 273 lbs.
2. A vertical line 2·3 inches long.
3. (*a*) 35·5 lbs.; (*b*) 10·5 lbs.
4. (*a*) total load = 8·75 cwts.; (*b*) 8·75 cwts.; (*c*) vertically upwards.
5. Horizontal.
6. See pars. 40–44.
7. (*a*) 10 ft. cwts.; (*b*) 5 ft. cwts.; (*c*) *nil*.
8. $5\frac{1}{2}$ tons, at 3·75 ft. from one end.
9. $10\frac{1}{2}$ cwts.
10. (*a*) 500 lbs. and 700 lbs.; (*b*) 575 lbs. and 775 lbs.

Examples to Chapter III (pp. 55-57)

1. See par. 78.
2. A vertical line 2·25 inches long.
3. Between the loads and 2·85 ft. from the smaller.

4. 1,485 lbs. ; the c.g. is ·93 ft. from the vertical face.
5. See par. 77.
6. 400 lbs. and 600 lbs.
7. (1) *O X* ; (2) *X B* ; (3) *B F* ; (4) *F A* ; (5) *A O*.
6. A vertical line 2″ long.
9. 3 cwt. acting vertically downwards.
10. (*a*) $P = 35$ lbs ; (*b*) 21 lbs. vertically downwards.

Examples to Chapter IV (pp. 82, 83)

1. The resultant of *A B* and *A D* ; equilibrant.
2. See par. 31.
3. 7 lbs.
4. Tension in longer cord, 10·8 lbs. ; in shorter cord, 14·4 lbs.
5. The direction of the reaction of the ground is found by joining the foot of the ladder to the point of intersection of the vertical through the c.g. of the ladder and the direction of the reaction of the wall ; magnitude of force = 156 lbs.
6. Vertical reaction = 100 lbs. ; horizontal = 173·20 lbs.
7. Horizontal reaction = 80·7 lbs. ; total reaction of top hinge = 262·7 lbs.
8. (*a*) − 34·64 lbs. and + 69·28 lbs. ; (*b*) both 34·64 lbs.
9. 1·28 ft. from inner face of wall.
10. $A B = 1{\cdot}25$; $B C = {\cdot}75$, both acting towards the point.

Examples to Chapter V (pp. 103–105)

1. Reaction of $A = 4{\cdot}5$ tons ; of $B = 10{\cdot}5$ tons.
2. $2{\cdot}2\dot{3}$ tons and $2{\cdot}2\dot{6}$ tons.
3. $47{\cdot}\dot{2}$ and $52{\cdot}\dot{7}$.

4. 1 ft. from the end.

5. $6{\cdot}1\dot{3}$ ft. from that end near which the force of 4 cwts. acts.

6. 2·25 lbs.

8. $A = 3{\cdot}625$ tons; $B = 1{\cdot}375$ tons.

9. $A = 3{\cdot}92$ tons; $B = 4{\cdot}58$ tons.

10. 14·25 tons and 11·75 tons.

Examples to Chapter VI (pp. 125, 126).

1. See par. 42.

2. By multiplying the lineal scale by the polar distance; $1'' = 40$ ft.-cwts. or $\frac{1}{4}'' = 10$ ft.-cwts.

3. 9 ft.-cwts.; 7·5 ft.-cwts.

5. 20 ft.-cwts.

6. See par. 183.

7. S.F. = 15 cwts.

8. B.M. = 18 ft.-tons; S.F. = 1·8 tons.

9. B.M. = 23 ft.-cwts.; S.F. = 8 cwts.

10. 2·9 cwts.

Examples to Chapter VII (pp. 159–161)

1. BF and $CF = 8{\cdot}96$ cwts.; $EF = 8{\cdot}01$ cwts.

2. BH and $EK = 75$ cwts.; CI and $DJ = 50$ cwts.; IJ, HI and $JK = 25$ cwts.; GH and $GK = 64{\cdot}95$ cwts.

3. BH and $EK = 90{\cdot}44$ cwts.; CI and $DJ =$ 60 cwts.; $IJ = 40$ cwts.; HI and $KJ = 26{\cdot}39$ cwts.; GH and $GK = 79{\cdot}79$ cwts.

4. BI and $FM = 80$ cwts.; CJ and $EL = 60$ cwts.; KH and $KD = 51{\cdot}96$ cwts.; JI and $ML = 20$ cwts.; JK and $KL = 10$ cwts.; HI and $HM = 69{\cdot}28$ cwts.

5. $BC = +\ 1{\cdot}44$; AC, AD, $DE = -\ 2{\cdot}88$; DC and $EF = +\ 2{\cdot}88$; $AF = -\ 5{\cdot}76$; $BE = +\ 4{\cdot}32$

tons. The horizontal reaction $= 5\cdot76$ tons; vertical reaction $= 2\cdot5$ tons.

6. BE, BD, $DC = +\ 4\cdot62$ tons; $ED = -\ 4\cdot62$ tons; $AE = -\ 2\cdot31$ tons; $AC = -\ 6\cdot93$ tons. The horizontal reactions $= 6\cdot93$ tons; vertical reaction $=$ 4 tons.

8. AJ and $IL = 0$; $AM = +\ 3\cdot625$; $BM = +\ 2\cdot09$; $DM = +\ 3\cdot97$; $FM = +\ 2\cdot38$; $HM = +\ \cdot79$; $IM = +\ 1\cdot375$; $CK = -\ 3\cdot03$; $EL = -\ 3\cdot18$; GL, DE, FG and $HI = -\ 1\cdot59$; EF and $GH = +\ 1\cdot59$; $AB = -\ 4\cdot18$; $BC = +\ 1\cdot87$; $CD = -\ 1\cdot87$ tons.

9. CI, DH, $EG = +\ 24\cdot5$; AI and $AG = -\ 25\cdot4$; $AH = -\ 24\cdot5$; IH and $HG = +\ 7\cdot0$ cwts.

10. $AJ, HY = 0$; $BL = -\ 104\cdot5$; $CN = -\ 176\cdot0$; $DP = -\ 214\cdot5$; $ES = +\ 197\cdot3$; $FU = -\ 148\cdot6$; $GW = -\ 82\cdot7$; $IJ = +\ 104\cdot375$; $IK = +\ 104\cdot5$; $IM = +\ 176\cdot0$; $IO = +\ 214\cdot5$; $IQ = +\ 221\cdot0$; $IR = +\ 221\cdot0$; $IT = +\ 197\cdot3$; $IV = +\ 148\cdot6$; $IX = +\ 82\cdot7$; $IY = +\ 82\cdot625$; $JK = -\ 148\cdot0$; $LM = -\ 101\cdot0$; $NO = -\ 55\cdot0$; $PQ = -\ 9\cdot5$; $RS = -\ 33\cdot75$; $TU = -\ 68\cdot7$; $VW = -\ 93\cdot0$; $XY = -\ 117\cdot0$; $KL = +\ 71\cdot4$; $MN = +\ 38\cdot4$; $OP = +\ 6\cdot4$; $QR = 0$; $ST = +\ 24\cdot0$; $UV = +\ 49\cdot0$; $WX = +\ 65\cdot63$ cwts. B.M. at $XY = 779\cdot75$ ft.-cwts.

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MAGNETISM.

EMBRACING

ELECTRO-MAGNETISM, MAGNETO-ELECTRICITY, THERMO-ELECTRICITY—DIA-MAGNETISM—WHEATSTONE'S TELEGRAPHS.

BY

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WITH NUMEROUS ILLUSTRATIONS.

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The Shepherd discovering the Magnetic Stone on Mount Ida with the Iron of his Crook.

MAGNETISM.

The magnetic or black oxide of iron, $Fe_3 O_4$, sometimes called the *lead-stone* or loadstone, is estimated as one of the most valuable ores of iron, because it enjoys the property, when freely suspended, of pointing to the north; and it does this by virtue of an inherent property which belongs to it, called magnetism.

The loadstone occurs native, and crystallizes in cubes, and is said to have been discovered by a shepherd on Mount Ida, who first noticed that the iron of his crook was attracted by it.

The magnet was not only called *magnes*, but "lapis Heracleus," from Heraclea, a city of Magnesia, a part of ancient Lydia, in Greece. It is also called *lapis nauticus*, because of its use in navigation; and *siderites* because the mineral attracts iron, which the Greeks called σιδερος.

"The earliest mention in English records of the primitive mariner's compass is that by Alexander Neckham, who describes the same in his 'Treatise on Things pertaining to Ships.' Neckham was born at St. Albans in 1157. A translation of his works, from the Latin, was published in 1866. In the reign of Edward III., the magnet was known by the name of the *sail-stone* or *adamant*, and the compass was called the sailing-needle or dial, though it is long after this period before we find the word compass. A ship, called the 'Plenty,' sailed from Hull in 1338, and we find that she was steered by the *sailing-stone*. In 1345, another entry occurs of one of the king's ships, called

the 'George,' bringing over sixteen horologies from Sluys, in Normandy, and that money had been paid at the same place for twelve stones, called adamants or sail-stones, for repairing divers instruments pertaining to a ship."

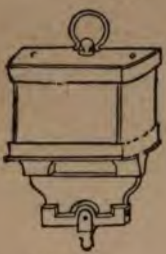


FIG. 1.
A mounted Loadstone.

Fine large pieces of loadstone are usually mounted in handsome brass or silver boxes, and were highly prized in the reign of King Charles II., when the Royal Society of England began to exert itself in the acquisition of scientific knowledge.

When examined with a magnetic needle, the mineral is found to have two points where the magnetic virtue exists in the greatest intensity: these are called poles, and are connected with the pieces of soft iron which protrude from the case containing the loadstone; they take off the friction and wear and tear of the mineral, whilst all cutting of the stone, in order to obtain a hollow space between the two poles, as in an ordinary horse-shoe magnet, is avoided. The magnetism from the loadstone is easily conferred upon and retained by hardened steel.

FIG. 2.—*Two Bars of Steel,*
Each marked N and S at their opposite extremities, and connected by pieces of soft iron, called "feeders."

It is only necessary to rub the steel or drag the loadstone round in one direction, taking care to put the pole N of the latter on the end of the steel bar marked S. An assemblage of steel plates in the form of an elongated horse-shoe, when carefully magnetised and fixed together, constitutes a kind of magnetic battery having greatly increased powers. (Fig. 3.)

FIG. 3.

This would be called a compound horse-shoe magazine or battery, composed of an odd number of horse-shoe bars of different lengths. The union of unequal bars produces a step-like arrangement at the poles, the largest bar being in the centre, with the pair of bars next largest on each side, and so on progressively. This peculiar arrangement, with all other magnetic instruments, may be obtained from Elliott, Charing Cross, and possesses several advantages, especially when used to confer magnetism on other pieces of steel.

The magnets (Fig. 4) bearing the name of Scoresby are composed of many magnetized, laminated-steel plates, combined together so as to act uniformly as one bar, by which means a powerful magnetic arrangement is obtained. A piece

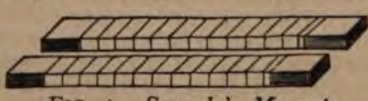


FIG. 4.—*Scoresby's Magnets.*

of steel, usually called a needle, when carefully balanced and suspended on a sharp point with a central hard metal cap, and then magnetized, is called a magnetic steel needle.

FIG. 5.

It is extremely useful for showing the influence of the magnetism of the earth as regards the horizontal-directive force, and is absolutely necessary in showing a repetition of the facts already explained in the article on "Static Electricity" (page 6), viz., that just as similar electricities repel, and opposite ones attract, so a north pole of a magnet repels the north pole of the magnetic needle, and the south behaves in a like manner with the south pole of the needle. Dissimilar magnetisms attract, therefore, the north pole of a bar magnet; one of those, shown at Fig. 2, will attract the south pole of the needle, and *vice versâ*.

At Elliott's may be obtained magnetic needles suspended in a beautiful manner, so that the needle moves either in a horizontal or in a vertical plane. When the needle moves in the horizontal plane, it is an ordinary mariner's compass; but when it is free to move in a perpendicular plane, it—however carefully balanced before magnetizing—dips downwards, and points to the earth like a finger-post, directing the eyes of the student to the terrestrial power of magnetism which causes the "dip."

FIG. 6.—*Needle suspended, and dipping towards the Earth.*

The direction of the horizontal magnetized needle not only varies daily, called "diurnal variations," but it has changed during various periods of years. *The magnetic needle* does not point due north and south, but in a plane or

direction peculiar to itself, called the magnetic meridian, to distinguish it from the true or terrestrial meridian. Magnetic meridian lines are planes passing through the centre of the earth in the direction of the magnetic needle. The terrestrial meridian is the plane passing through the same place on the axis of the earth.

The angle made by these two planes is called the *declination of the needle.* It is determined by measuring the angle which the direction of the needle makes with the meridian line. The declination was eastward at the beginning of the 17th century; it was zero, or 0, in 1660, *i.e.*, the needle pointed due north and south. The declination now changed to the westward, and had increased to 24° 30′ in the year 1818, since which period it has steadily retrograded, and about ten years ago had reached 21° 48′ in London.

It would appear from the observations set on foot many years ago by General Sabine, that the sun and moon are magnetic, and do affect the needle in its diurnal movements.

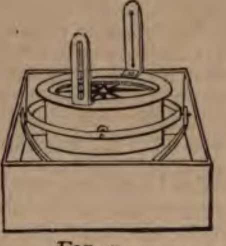


FIG. 7.

The marine compass only differs from the ordinary one in being suspended in such a manner that the motion of the vessel shall not disturb its horizontal position. The marine azimuth compass (Fig. 7) is a more elaborate mariner's compass, having within the circumference of the inner box sights for determining the angular distances of objects from the magnetic meridian, and being hung in detached gimbals.

The dipping needle or inclination compass is also found to vary as the dip increases, as might be expected, the nearer we approach to the north pole. At a point in 70° 5′ of north latitude and 96° 46′ west longitude on the west coast of Boothia Felix, a place was discovered by Captain Parry (the north magnetic pole) where the dipping needle became vertical, and the horizontal compass ceased to move right or left, or traverse. Captain James Ross discovered the other end of the great terrestrial magnetic power, the south magnetic pole, to be about latitude 73° south and longitude 130° east.

The student may realise such movements of the dipping needle by laying one of the bar magnets (Fig. 2) in the centre of a sheet of cardboard on which a circle has been described.

On moving the dipping needle round the circle, it will be found to take the vertical position at the poles A A, whilst it becomes horizontal at the equatorial position B B, *i.e.* midway between the north and south pole.

The inclination or dip varies like the horizontal declination. At London, it was 70° 27′ in 1720, 69° 2′ in 1833, and 68° 51′ in 1849; at the present time it is about 68° 30′.

The earth being virtually an enormous magnet, whose north pole is in the southern hemisphere, and *vice versâ*, must affect all ferruginous matter on the earth by induction.

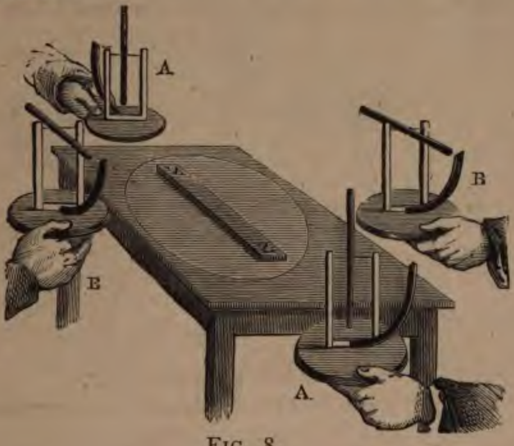


FIG. 8.

It was stated, in the article on Electricity, that the term induction would have to be used again; and the student is reminded that this is defined to be the magnetic influence set up by the mere neighbourhood or proximity of a body—the earth, or the loadstone, or a magnetized steel bar—having or possessing the magnetic virtue or force.

By placing variously shaped pieces of soft iron near a powerful magnet, they are supported or attracted so long as the magnet is kept sufficiently near them; but, as the distance is increased, they drop off one by one.

FIG. 9.—*Variously shaped pieces of soft Iron for showing Induced Magnetism.*

The magnetic power so quickly conferred on soft iron is as rapidly lost when it is removed from the disturbing cause, reminding one of conductors of electricity, which cannot maintain polarity; whereas steel, which acquires magnetic power more slowly, retains it with a tighter grasp, and, like non-conductors of electricity, glass, wax, &c., can maintain magnetic polarity.

On the supposition that all terrestrial magnetism has an electrical or-
and is produced by currents of electric force which circulate around the glo
a very pretty piece of apparatus is constructed, consisting of a distribution
wires, covered with silk, over a terrestrial globe in parallel lines of latitud

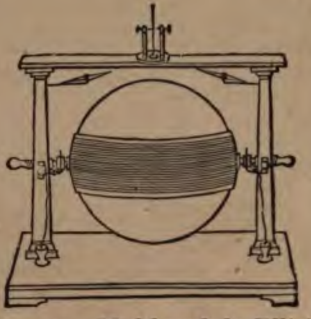


FIG. 10.—*Model made by Elliott,*

Showing that electrical currents circulating around a globe produce magnetic currents.

The dipping needle and horizontal needle held in different positions on surface of the globe, whilst the wires are connected with the voltaic batt give the student a very good notion of the natural directive power of magnetism that exists over the surface of the earth on which we live, and a illustrates again the "*inductive*" power of magnetic force.

The force which rules the position of the magnetic needle is neither attr tive nor repulsive, but simply directive. A magnetic needle floating on a c neither advances nor moves backward; it simply takes a position nearly no and south, and places itself in the magnetic meridian.

The engraving, Fig. 12, is a correct copy of the photographic curves the self-registering "Declination Magnetograph," as used at the Magn Observatory at Stonyhurst College, near Blackburn.

This is one of a series of magnetic instruments which are self-register night and day; and it is interesting to notice in the photographic curves amount of disturbance shown between the 8th and 10th of August, 1868. T instruments are under the charge of the Rev. S. G. Perry, who has most kin furnished the following drawing and description of the Magnetic Observat at Stonyhurst:

"An idea of the disposition of the instruments may be formed from drawing (Fig. 11), and a very brief description will make it still more cle:

"The instruments record the oscillations of three magnets suspended un the glass shades; and we thus get completely all the changes, both as to dir tion and intensity, in the earth's magnetism. The magnet which is to right in the sketch is suspended by a silk thread in the magnetic meridi and, by the aid of a mirror attached to it, describes on a cylinder, which is pu motion by the clock on the centre pier, all the variations in the magnetic clination. The other two magnets give the two components of the to magnetic force of the earth. That which records the variations of the verti

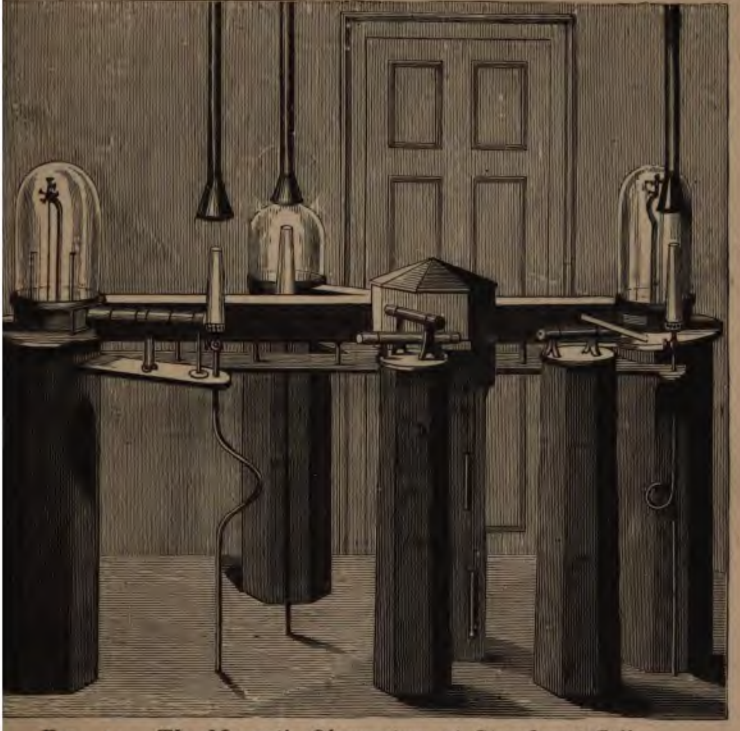


FIG. 11.—*The Magnetic Observatory at Stonyhurst College.*

nponent rests, under the shade near the doorway, on two agate edges; ilst the horizontal-component magnet is suspended by a double steel thread, ler the shade to the left of the picture, and is held nearly at right angles to magnetic meridian by the torsion of the thread.

'Under the clock-box, which stands in the centre, are the three cylinders ered with sensitive paper. To each magnet is attached a semicircular ror, which sends the rays from a jet of gas to one of the cylinders in the ck-box, and thus describes, by a curved line, all the oscillations of the gnet. A second semicircular mirror is fastened to the pier on which the trument stands, and, describing always a straight line on the cylinder which pposite to it, gives the zero line for the curve.

'These magnetographs were constructed by Mr. Adie, and are similar in rly every respect to those made for the Kew Observatory, under the direc- n of Mr. Welch.

'The *magnetic room* is built underground to prevent sudden changes of

FIG. 12.

temperature, and we have been s
tunate that the daily range is sc
over 0·2°."

It is curious that every kind of
tion assists the magnetization o
or steel by terrestrial magnetisn
half-a-dozen iron wires, 12 or 15
length, are twisted strongly to
whilst held in the direction of
ping needle, viz. 68°, they becom
magnetic, and, having now di
poles, will affect a magnetic needl
a steel-bar magnet. Iron col
guns, the plating of ships of war
goes of iron or steel, all acquire
netic power; and, until this fac
understood and provided for,
disastrous shipwrecks were caus
the compass pointing in the wro
rection, and thus conducting th
fortunate ship to the rocks, inste
keeping her in mid-ocean. Mr. B
has devised certain means by whi
compasses of ships may be corr
and the influence of local ma
attraction, due to the guns, or sh
other iron or steel cargo, neutraliz
that the "*directive*" force of terr
magnetism alone shall guide the
over the pathless ocean. A lat
lamented friend of the writer (Mr.
Hopkins) tried a vast number of
riments, and wrote an interesting
phlet on terrestrial magnetism, wi
ference to the compasses of iron
their deviation and remedies.

It is impossible in our limits
justice to the arguments brough
ward and discussed by Mr. Ho
but the remarks made at the ter
tion of the debate at the Royal U
Service Institution on his pape
give the reader some notion o
opinions entertained by the m
on the method of destroying th
larity of iron ships, as proposed b
Hopkins.

"Sir FREDERICK NICOLSON:
subject has been treated in an em
ly practical way. In the abstr
Mr. Hopkins's papers, I find that

ie statement which appears to me the most important, that is, Mr. Hopkins he is prepared to destroy the polarity of any given ship in ten minutes. only question I wish to ask, because the gist of the paper lies in that rtion, is whether Mr. Hopkins has performed that operation upon any ship.

Mr. HOPKINS: No, not in any ship as yet; but I have made experiments ong bars and plates of iron, and I am quite satisfied that I can produce same results on the iron plates of a ship. In reply to the observations ch have been made I will not detain you long, because I do not think the arks made require lengthy replies. First, with regard to Sir Edward cher's remarks, he said that I stated that there was no magnetic pole. I not state that there was no magnetic pole; on the contrary, I have endeared to explain that *the entire areas bounded by the antarctic and the arctic les are the great magnetic poles of the earth*, towards which all the magnemeridians converge. I do not mean to say for one moment but that a ping needle at the north latitude of 70° approached nearly 90°, observed Sir James Ross, and probably over a great number of square miles in that ion; but I have seen dipping needles approaching 90° near the equator. ere are many places in the islands of Scotland, also in Norway, Sweden, Russia, where the dipping needle will not only approach 90°, but remain 90°. Therefore I repeat that the dip of the dipping needle does not necesily depend on the action of the terrestrial pole, but on local attraction. ides, neither experiments, analogy, nor observations on the magnetic idians support the notion of the magnetic pole being merely a mathemal point near Boothia Gulf. We have only to prolong the observed magnetic idians to the circle of 70° of latitude to show the fallacy of the Boothian e. We must be guided by the *meridians* of the needles to determine the ition of the active polar areas. Go to Norway; go to Sweden; where do needles point? Do they point to Boothia Felix? No; they do not. ey point towards the arctic region, and not to any special *point*. With ard to the other point that Sir Edward stated with reference to the coms, I do not believe there is a possibility for the compass to point correctly ess it be left entirely under the control of the great terrestrial force: any erference, whether by magnets or electric appliances, can only increase the fusion and danger, and therefore the compass should not be tampered h, but left to act freely and under the sole influence of terrestrial magnetism. th regard to what Captain Selwyn stated about the steering compass. He d, 'Never mind that; I believe you do not care much for the steering coms; you go by the standard compass.' Well, there is now always a difference ween the standard and the steering compasses. We know that in iron ps that difference constantly varies. You do not know what the variation that is constantly going on. Were you certain of the exact amount of iation, it would be like the watch and chronometer spoken of by Captain lwyn; but you cannot compare the case of your watch and chronometer h those of the standard and steering compasses when you have an iron sel, and where you have a perpetual change going on in the action of the arity of the iron vessel. With regard to the reflector, I see Captain Selwyn prehends difficulty. I see none, and the appliance is already appreciated several experienced captains. I do not think there would be much diffity in seeing a compass, with a good strong light, with a 12-inch card at a tance of even 30 feet. However, I leave that to others. There is one thing Edward Belcher mentioned with regard to the needles. I am perfectly

familiar with all the needles they use in high latitudes. They are u
worthless in *directive* power. As to the dipping needles, they have no
tive power whatever, and, as justly observed by Captain Fishbourne, ha
lateral directive power at all, and cannot therefore serve as guides to
mine questions connected with *meridian lines*. The *curved* magnetic n
will act where neither the straight nor the dipping needles can be ren
serviceable in high latitudes. It only remains for me, in conclusion, to t
you for the patience and kindness with which you have listened to the o
vations I have made.

"The CHAIRMAN: I am sure there will be but one opinion among y
to a vote of thanks to Mr. Hopkins for the very interesting paper he has
He has brought forward some of the old ideas relating to magnetism, v
many here were not acquainted with, and he has given us some new ide
must say that his idea with respect to the bent needle is one which I thi
deserving of a trial. I must also say I should like to see that dissipati
the polarity of a ship tried, although I am afraid that the soft iron of the
would become magnetised by some other extraneous cause at presen
known. I really believe this, although we are very thankful to him for
he has told us, that we shall still find it positively necessary to have rec
to observation. I hope what you have heard to-night will strengthen
confidence in the compass as a means of steering. There is another re
about the pole. As I have passed within 70 miles of it, and the dip wa
47″, I must say that I can only look upon the pole as capable of being de
not perhaps exactly as a point, but very nearly as a point, because as I p
up, I changed from 89° 47″ north dip to 89° 46″ south dip. With resp
the deviation of the compass, it has been an old thing with us who have
in high latitudes. We know perfectly well that we suffer the same in
venience which is experienced now in iron ships. In Behring's Strai
going about there, the deviation of the ship amounted to six points of the
pass; and I can say, which I have no doubt Captain Maguire will corrob
me in, that we should have had the greatest difficulty in the world to tak
ships up into the position we did, if it was not for the admirable cha
Admiral Bechey, and in which expedition Sir Edward Belcher served. T
is only one other point. I will say that I have listened to this paper w
great deal of gratification and pleasure, because, during the course o
service in the Arctic regions, it so happened that for two years I was not
to use a compass at all; therefore, I am able to appreciate anything tha
increase the value of it."

The sequel is soon told, for Mr. Hopkins caught a violent cold w
engaged in attempting to depolarise one of the iron-clads; and, althoug
partially recovered, his system received a shock which ended in death.
kind and enthusiastic spirit was spared the disheartening report of the
success of his method, subsequently brought before the Royal Society.

Mr. Barlow corrects the local magnetic power of the iron of the shi
placing a piece of soft iron in a particular position, so as to compensat
the derangement of the compass produced by the anchors, chains, guns,
of the vessel.

Amongst the latest practical applications of magnetism to useful pur
is that of Mr. Saxby, who proposes to test the iron of guns by magnetic p
Mr. Paget, C.E., *in a very able paper in* "The Engineer," thus reports o
process or method of Mr. Saxby for testing iron·

"It is well known to engineers that it is a most difficult and often impossible thing to find out the existence of a false weld in a forging, or of a blowhole or honeycomb in an iron or steel casting. The only safe way of doing this is by carefully measuring the elongation of the piece under a given load, as with a false weld all the work is thrown on the diminished area at the defective weld, and the thicker parts are scarcely extended by the force which is perhaps rupturing the bar at the flawed spot. It need scarcely be said that there are many important cases where this process, or the equivalent but dangerous one of trying the effects of an impulsive force, could neither be mechanically nor commercially practicable. Every one knows that a simple method by which internal flaws and solutions of continuity in constructive details could be easily detected would be of enormous value to the world. Such a method has undoubtedly been discovered by Mr. S. M. Saxby, R.N., who has very judiciously been allowed by the Admiralty, during the course of this year, to experiment with it in the royal dockyards. Though comparatively new, and not yet completely worked out, the process will possibly have a yet more extended application than finding out only mechanical flaws in iron, and possibly in cast iron and steel.

"The principle upon which Mr. Saxby's method is founded is so simple that it certainly seems strange that it had previously escaped notice. It has been known for nearly a century and a half that when a bar or any mass of soft iron is placed in the position of the dipping needle, it is at once sensibly magnetic, the lower extremity being a north pole in our latitudes, and the upper extremity a south pole. In the southern hemisphere the poles are of course reversed. The same action, only weakened, takes place in a bar hanging in a vertical or any other position; only the effect is weaker the more the position of the longitudinal axis of, for instance, a long bar departs from that of the magnetic dipping needle.

FIG. 13.

"When, therefore, as in Fig. 13, a small compass needle is slowly passed in front of a bar of very good iron, placed in an east and west direction, the needle will not be disturbed from its proper direction, which is of course at right angles to this, or north and south.

"All this refers to regularly homogeneous bars of best quality—to bars without any mechanical solutions of continuity. With internal flaws or interruptions of continuity the bar is no longer regularly magnetic. It has long been known that a good compass needle, or a good permanent magnet, must be homogeneous and without flaws in order to take and retain its maximum amount of magnetism. In a word, *any mechanical solution of continuity is accompanied with a polar solution of continuity*, and the given bar or mass *with flaws—whether* permanently magnetized or temporarily so by the induc-

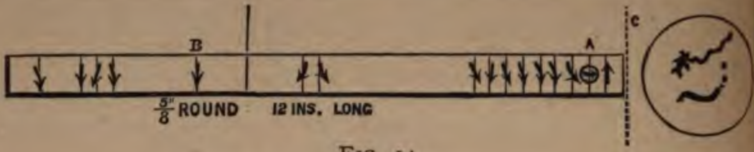


FIG. 14.

tive action of the earth—is no longer one regular magnet, but several different magnets, with the different magnetisms separated from each other. The delicately-poised magnet of a compass can thus be made to tell the presence of such solutions of continuity. The above drawing (Fig. 14), showing the actual results of the test with a $\frac{5}{8}$ in. bar, 12 in. long, will illustrate the manner in which the compass magnet is affected by the presence of cracks, of solutions of continuity, in the bar, which is supposed to be lying in the equatorial magnetic plane, or east and west.

"By the enlightened permission of the Admiralty Board, Mr. Saxby, as stated, has already been allowed to test his method in various ways in the royal dockyards of Sheerness and Chatham, and we will describe some of the practical results of these experiments. Amongst these were a number of very remarkable trials conducted in the presence of the master smiths, the foremen of the testing-houses, and several of the chief engineers of the royal navy.

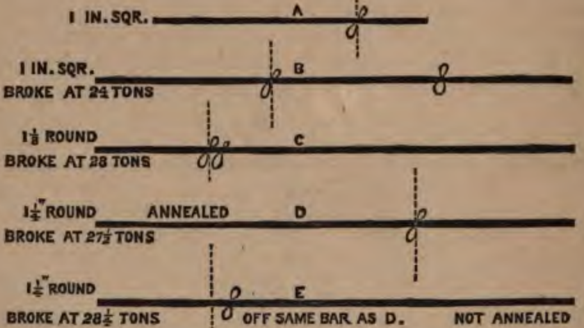


FIG. 15.

Mr. Saxby, for instance, was requested to find out the weakest spots in a number of bars, and to tie a string or make a chalk mark on each spot. Immediately afterwards all these bars were put into the testing machine and broken. Their history is given above, in the annexed cuts (Fig. 15), the prediction having in every case been verified. The bars are shown by lines to scale, and a scroll is placed where the weakest part was found out by the needle. The vertical dotted lines indicate the spots where the several bars broke.

"The smiths of the royal dockyards seem to have properly tried Mr. Saxby's powers in almost every possible way, and most ingenious devices were some-

times resorted to for the purpose. As examples out of many, in the centre of a bar (Fig. 16) of 1 in. square forged iron was welded a piece of unmagnetized steel about 5 in. long. The needle detected a fault at about the centre of the piece of steel.

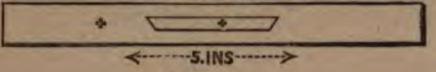


FIG. 16.

"Now Mr. Saxby's method can detect the presence, and negatively of course the absence, of small or large solutions of continuity. It can detect false welds, smaller flaws caused by bad workmanship or wear, and, we believe, what is commonly termed 'crystallization,' which will, probably, at once be generally acknowledged to consist in a disruption or parting of the facets of the amorphously arranged crystals of which iron is built up. It can, of course, only detect the results of the chemical constitution of iron, as evidenced in the less perfect cohesion of the crystals when alloyed, in relatively considerable quantities, with foreign bodies. There is little doubt that the magnetic method is a test of the homogeneous character of the iron and of its freedom from fissures and cracks, and so far it undoubtedly forms a test of quality. It will appear scarcely credible that a common pocket-compass needle should be able—almost like the divining rod said to be used for finding out springs of water—to discover important defects in large iron bars. A mere statement of the fact does sound almost incredible until the simple means actually employed are explained."

Amongst the influences which open the pores of the steel, as it were, to receive a full charge of magnetic force is that of heat, and it is found that when steel is made red hot, and allowed to cool in the direction of the magnetic dip, it acquires more quickly and largely the magnetic charge.

It was contended by Mrs. Somerville that unmagnetized needles were magnetized if exposed to the violet ray of the spectrum; but Riess and Moser have shown that these effects only take place when the needle is perpendicular to the magnetic meridian, facilitated by the heating of the needle, first by exposure to the violet rays, and secondly and more especially by the subsequent cooling.

A powerful steel magnet, heated to a white heat, loses its magnetic power. Red-hot iron is no longer rendered magnetic by induction.

Nickel, raised to the temperature of boiling oil, loses its magnetic virtue.

It ought to be mentioned here, that certain metals, nickel and cobalt, have distinct magnetic powers; and Sir Charles Wheatstone has given a very ingenious and elegant method of detecting minute quantities of magnetic force. He says—

"If a short sewing needle, A (Fig. 17), the eye end being broken off, rest upon its point on the polar surface of a powerful bar magnet, it will generally take a position inclined to the surface; but a locality may generally be found in which the needle will stand nearly vertical; this point may be ascertained by placing a piece of unglazed paper, D, between the needle and the magnet, and moving it about until the vertical position of the needle is obtained.

"If we elevate the paper and needle above the magnet to the greatest

distance at which the needle will remain vertical, it becomes to the last degree sensitive of magnetic force; so that by bringing specimens of nickel or cobalt, which have the least magnetic power, or any impure metal, such as a specimen of metallic manganese, which Faraday thought he had proved (when entirely free from iron) does not indicate the slightest magnetic power,* or rhodium, iridium, or hammered brass, if the latter metals contain any iron, they will affect Wheatstone's test needle, but not otherwise."

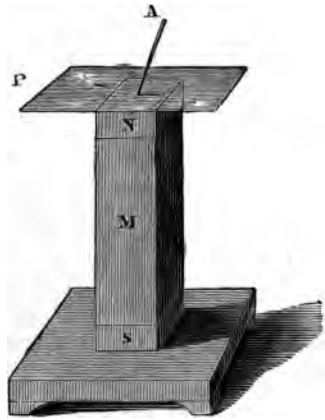


FIG. 17.

There are other influences that may affect the magnetic needle. When a plate of copper is rotated quickly (say 800 revolutions per minute) beneath a suspended magnet, the latter also is thrown into rapid rotation.

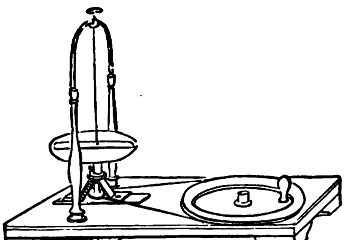


FIG. 18.

might be thought that this was brought about by the motion of the air; the same effect occurs even when the copper plate rotates in a vacuum, wholly screened by glass from the magnetic needle.

* See Dia-magnetism, for further information.

The apparatus (Fig. 19) exhibits this curious property of metallic plates in motion, and is usually made by Elliott with a variety of metallic plates, all of which, when spun round rapidly, first cause the magnetic needle to deviate from its natural position, and then finally to assume rotation.

When the experiment is reversed, and a compound bent magnet is caused to revolve with great velocity about its axis of symmetry, and below the metallic plate, which is carefully suspended, then the latter commences revolving in the same direction.

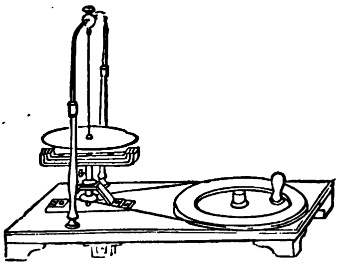


FIG. 19.

All these experiments have arisen from the original one performed by Arago, who first tried the effect of a ring of copper upon the oscillation of a delicate magnetic needle which it enclosed. In free space the magnet performed 420 oscillations before it reached an arc of 10°, whereas, when surrounded with a copper ring, they were reduced to fourteen oscillations; under the same circumstances in a ring of wood, the oscillations were reduced from 420 to about 300.

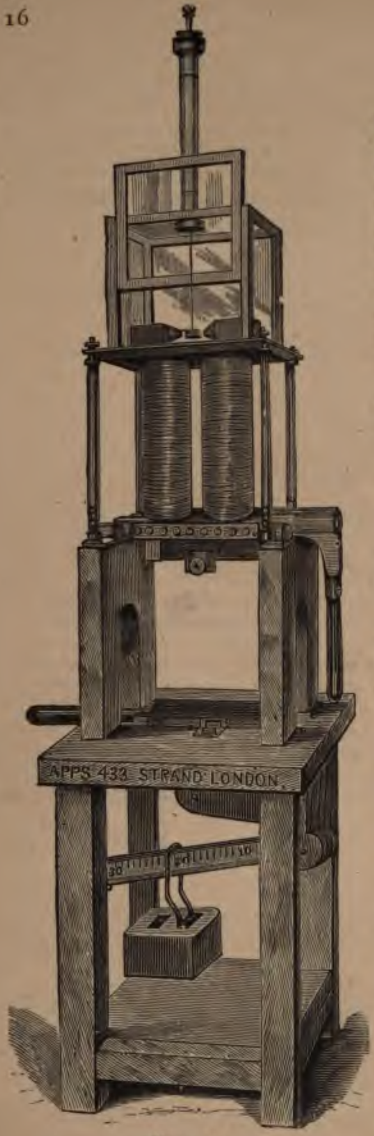


FIG. 20.
Apparatus made by Mr. Apps,
Which may be used either for dia-magnetic experiments or to show the enormous weight which can be supported by a powerful electro-magnet.

DIA-MAGNETIS

In the preceding chapter, it
pointed out that the loadstone,
steel, cobalt and nickel, poss
nary magnetic powers, and ca
or repel a magnetic needle.
now in the beautiful experim
made by Faraday to consider
netic powers of other substa
shall discover that a vast n
bodies are affected by magnet
produced by and circulating
to pole of a very powerful ele
net, such as that depicted at

The dia-magnetic apparat
cially designed to illustrate
celebrated experiments on the
netism or para-magnetism o
and the effect on light in th
of the plane of the polarized

Besides these very exten
varied applications, the act
power of the electro-magnet
found by turning the poles do
when they face the armature
with the compound-lever arra
The power obtained with a s
of Bunsen's, of very small siz
5 cwt., and with twenty Gro
this magnificent apparatus
tons. It was exhibited b
Royal Society, April, 1868.

In the experiments, which
sently be detailed, there are c
sitions constantly referred t
positions which various bo
assume between the poles of t
magnet (Fig. 20). Thus t
between the two poles is called
netic field, and a straight li
from pole to pole, like the po
earth, is called the axial line,
the imaginary line around
earth rotates, called its axis.
subjected to the action of the
current is said to place itse
when it takes the above direc
however, the body under e
takes a position at right ang
direction, it is said to point *equ*
Thus, in Fig. 21, the poles
sented by pieces of soft iro

FIG. 21.

off to a rough point; and if a rod of iron is suspended between them and the electro-magnet connected with the battery, the rod takes up an axial position, whilst a similar rod of bismuth, also suspended by a filament of silk, places itself at right angles to that position, as is shown at Fig. 22.

FIG. 22,

In all these experiments the poles of the magnet, with their soft-iron armatures, are surrounded with a glass box, like the lantern of a balance, to prevent the action of currents of air. Faraday discovered that when the crystals or solutions of salts of metals that are magnetic, such as ferrous sulphate, are placed in a glass tube which is not magnetic, they do, as a general rule, place themselves axially. Cobaltous and nickelous sulphate behave in the same manner; and this axial position is always maintained, provided the metal enter into the *basyl* of the salt.

FIG. 23.—*The Cube of Bismuth taking the Equatorial position.*

When a single pole of the electro-magnet is used, repulsion takes place with very many bodies, and, of course, if the substance is repelled by both poles when placed in the magnetic field, it will take a place at right angles to the magnetic current, or the equatorial position.

Phosphorus, bismuth, and antimony—the first a non-conductor of electricity, and the second and third metals therefore conductors—are each and all repelled from a single pole, or place themselves in the equatorial position between the two poles.

It is most amusing to twirl a suspended halfpenny between the poles of the electro-magnet (Fig. 24). Of course this may be done as often or as long as the experimenter pleases; but if, whilst the coin is rotating, the electro-magnet is connected with the battery, the halfpenny stops dead, and instantly places itself in the equatorial position.

FIG. 24.—*The Halfpenny twirled, then stopped by the magnetic force.*

The preceding experiments show that those bodies which are not magnetic will exhibit dia-magnetic properties, *i.e.*, they are substances through which the lines of magnetic force (represented by the beautiful curves assumed by iron filings when sprinkled on a sheet of cardboard held over the poles of a powerful magnet or, still better, an electro-magnet) pass without affecting them like iron, cobalt, or nickel.

This mode of experimenting is more delicate as a test for magnetism than the use of the needle, already alluded to at page 14. FIG. 17.

And it was by taking solutions of pure salts of manganese and chromium, and placing them in the magnetic field, that they were discovered to be magnetic, whilst as metals it was so difficult, if not almost impossible, to obtain them in the pure state and free from iron. (Fig. 25.)

FIG. 25.

Faraday, always so exact and orderly in his classification and nomenclature, proposes to include all the phenomena under one general title, viz., that of magnetism, and to subdivide this into para-magnetic and dia-magnetic phenomena. A very long list, originating with Faraday, has therefore been framed on this principle.

Para-Magnetic, usually called Magnetic.	Dia-Magnetic.
Axial.	Equatorial.
Manganese	Lead
Nickel	Cadmium
Cobalt	Sodium
Iron	Mercury
Titanium	Zinc
Palladium	Tin
Cerium	Bismuth
Chromium	Antimony
Platinum	Arsenic
Osmium	Silver
Paper	Gold
Sealing-wax	Copper
Berlin porcelain	Tungsten
China ink	Uranium
Plumbago	Rhodium
Peroxide of iron	Iridium
Fluor spar	Alum
Asbetos	Glass
Silkworm gut	Rock crystal
Red lead	The mineral acids

Para-Magnetic, usually called Magnetic.	Dia-Magnetic.
Axial.	Equatorial.
Sulphate of zinc	Litharge
Shellac	Phosphorus
All sorts of iron,	Common salt
where the latter	Nitre
is basic	Sulphur
Vermilion	Resin
Tourmaline	Spermaceti
Charcoal	Iceland spar
Oxygen, which	Tartaric acid
stands alone as	Citric acid
a para-magne-	Water
tic gas	Alcohol
Salts of chromium	Ether
Salts of manga-	Sugar
nese	Starch
Oxide of titanium	Gum arabic
Oxide of chro-	Wood
mium	&c., &c.
Chromic acid.	

Nitrogen.

Nitrogen is like a vacuum—it is neither para-magnetic nor dia-magnetic; it is, in strict reason, like space, with reference to these experiments; it is a zero, or a starting-point.

The magnetic or dia-magnetic property of a body, curious to say, varies according to the medium in which it is placed: thus, a glass rod, suspended horizontally in water, which we find, with glass, in the dia-magnetic column, points axially, like any ordinary magnetic body; but if the same glass rod is suspended in a solution of ferrous sulphate, a magnetic body, it points equatorially.

The magnetic-field test discovers whether a metallic salt has the metal in the basyl, the basic, or electro-positive state; or whether the metal is simply a part or constituent of the acid or electro-negative compound. Iron is basyl in ferrous sulphate, and sets axially, and is para-magnetic; but in potassic ferrocyanide it forms part of the ferrocyanic acid, and therefore the crystal sets equatorially, and is dia-magnetic.*

The reader will find all the apparent exceptions and peculiarities attending their structure in Tyndall and Knoblauch's paper (Phil. Mag., 1850, vol. xxxvi., p. 178, and xxxvii., p. 1). The same gentlemen have discovered that dia-magnetic repulsion is as the square of the intensity of the current; and Reich, Weber, and Tyndall seemed to have proved that which foiled Faraday, viz., that bodies under dia-magnetic influence exhibit polar characters. The polarity is the reverse of all other polarities, electrical or magnetic: the feeble polarity of a dia-magnetic substance is the *same* as the pole of the magnet in its neigh-

* The same test will discover, for instance, in a roll of paper, whether it contains iron or not: if it contains the metal, or is coloured blue with cobalt, it will set axially, because iron and cobalt are magnetic, or, to use *Faraday's* phraseology, para-magnetic.

bourhood; whereas we have learnt that north induces south magnetism in a piece of iron, and vitreous electricity induces negative in the body to which it is approached.

The dia-magnetism of gases was first shown by Father Bancalari, of Genoa, who discovered that flame, such as the flame of a candle, was influenced by the poles of a powerful electro-magnet.

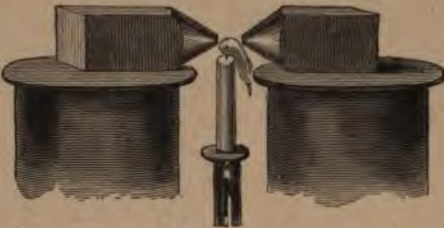


FIG. 26.—*Effect of the Poles on Flame.*

Faraday tried Bancalari's experiment, and found that when the axial line of the magnet was horizontal, and the flame of a taper held near it, and on one side or the other, with about one-third of the flame rising above the level of the upper surface of the poles, the flame seemed to be repelled away from the axial line, moving equatorially until it took an inclined position, as if a gentle wind was acting upon it, and causing its deflection from the perpendicular line.

It was the flame experiments which led to the discovery of the magnetic property of oxygen, and of the dia-magnetic properties of atmospheric air, nitrogen, hydrogen, coal gas, olefiant gas, &c.

Faraday showed that soap-bubbles, filled with various gases and blown from the end of a capillary tube, were either attracted or *repelled* according as the gas was magnetic or dia-magnetic.

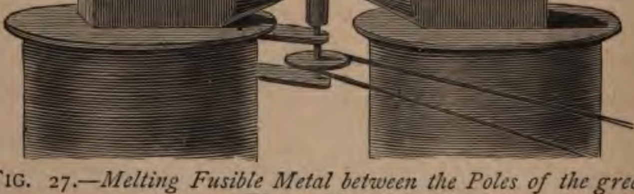


FIG. 27.—*Melting Fusible Metal between the Poles of the great Electro-Magnet.*

One of the most curious experiments which may be performed with the dia-magnetic apparatus is that of overcoming the equatorial or para-magnetic force by physical power. The twirled penny-piece brought to rest between the poles, if forcibly turned round, will by the motion generate heat, and may be made very hot.

If a brass tube, containing some solid fusible metal, composed of two parts by weight of bismuth, one of lead, and one of tin, with a few drops of mercury, is rotated very fast by a whirling-table wheel between the poles of the powerful magnet, no effect is produced until contact is made with the battery, and then the rotation or motion is speedily converted into heat, and the fusible metal is melted as if it had been held over the fire. Here again is a perfect *conservation of force*. The heat which melted the alloy is the exact equivalent of the chemical power of the battery used, although it acts by an intermediate force, viz., magnetism; but the chemical action produced the electricity, the current electricity produced the magnetism, and, the magnetic force which tends to keep the bismuth in the alloy in the equatorial position being overcome and resisted by physical force, the muscles of the arm acting on the whirling table eliminate heat.

Faraday thought he had proved, by using heavy glass and permitting a ray of polarized light to pass through it, that the ray was affected by the powerful magnetic force eliminated from the great electro-magnet. Faraday's glass consists of a mixture of silicate and borate of lead, and is much denser than ordinary glass. If a ray of polarized light is allowed to pass through it, and is then examined in the ordinary manner with an analyzing plate or a bundle of plates of glass, or by a tourmaline or a Nicol's prism, the light, of course, disappears, as already explained in the article on Light, when the plane of reflection from the analyzing plate is at right angles to the plane of polarization. (Fig. 28.)

FIG. 28.

If now the battery is connected with the electro-magnet, between the poles of which the bar or cube of Faraday's dense glass is placed, the light re-appears instantly, again disappearing when contact is broken with the battery.

Matteuchi found that the effect was increased by increasing the temperature of the cube of heavy glass to 600° Fahrenheit; and he also ascertained that by subjecting the heavy glass to pressure he could change the direction of the ray of polarized light, as Faraday had done. So that, in fact, Faraday was wrong; the magnetic force did not act upon the ray of polarized light, but on the molecules or particles of the glass, which were under a strain during the time they were subjected to the action of the powerful electro-magnetic force.

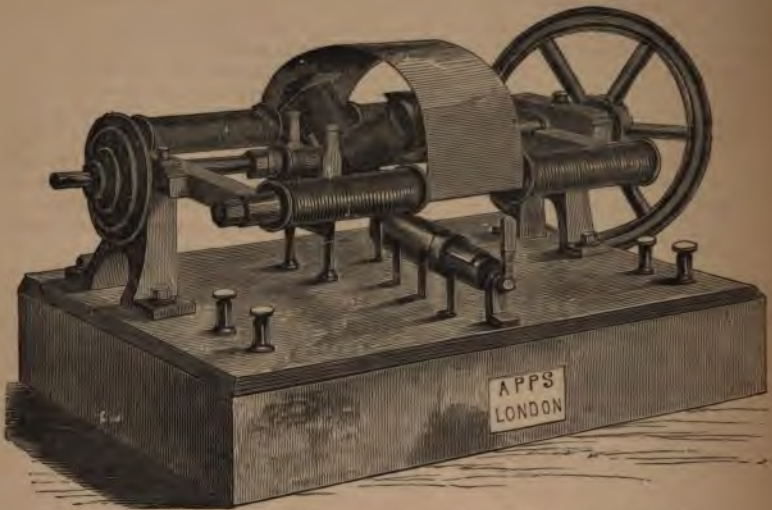


FIG. 29.—*Apps's half-horse power Electro-Magnetic Engine.*

ELECTRO-MAGNETISM, MAGNETO-ELECTRICITY, THERMO-ELECTRICITY.

In 1820, Œrsted, a Danish scientific man, discovered the connection between electricity and magnetism. It was not found where philosophers sought for it. They thought to imitate Nature; and as some steel knives were found to be powerfully magnetic after a discharge of lightning had passed through a box containing them, they subjected other pieces of steel to the discharge of powerful Leyden batteries without producing the effect they expected.

Œrsted found that the electricity must be in motion, or in a dynamical state, such as it would be in when evolved from the voltaic battery.

Static electricity will, under certain arrangements to be hereafter described, magnetize steel; but the mere fact of allowing a wire charged with statical electricity (the force from the electrical machine) to approach a magnetic needle does not affect the needle like the same wire conveying a current from a single voltaic circuit or, still better, a battery.

M. Ampère, who took up the subject directly after Œrsted had published his discoveries, laid the foundation of the science of electro-dynamics. He discovered that every part of the whole circuit—the wires, the terminals or poles, the battery, in fact, all parts—exercised a magnetic power upon the magnetic needle. He also proved that the force was in an eminent degree one of *circulation.* Ampère made himself fully understood by asking his readers to conceive a man lying down in the circuit, so that the wire lies along his face

and body. We are now to suppose that the current enters the wire at his feet and goes out at his head, and that his upturned face and eyes are directed to a magnetic needle suspended parallel with and over the wire conveying the electric current, so that the north pole of the needle points to his face. Directly the current passes, the needle is deflected to his left hand; and by reversing the direction of the current, and causing it to flow into the wire at his head and out from his feet, the needle will now move to his right hand.

FIG. 30.—*Wire conveying a Current of Electricity affecting the Magnetic Needle.*

Thus every possible variation may be imagined as long as we maintain the same relative positions of the wire and the human body; and it was further ascertained that the intensity of the electro-magnetic force is in the inverse ratio to the simple distance of the magnetic needle from the current; or, in other words, that the elementary action of a simple section of the current upon the needle is in the inverse ratio to the square of the distance.

If a single wire can affect a magnetic needle, it is evident that by doubling and trebling the wire, or winding it round in a helix, the effect must be enormously increased, provided the coils of wire do not touch each other, or are covered with some non-conducting material, such as silk or cotton; hence it is that coils of wire are constructed so that a piece of soft iron placed

FIG. 31.

inside the core becomes a most powerful magnet directly contact is made *with the battery.* When the immense power of the electro-magnet was asce

tained, great anticipations were formed of the application of this force as a motive power. It is not surprising that this should have been the first conclusion. Thus the great electro-magnet, made by Mr. Apps, that heads the chapter on Dia-magnetism, will lift five hundredweight with a single quarter-pint Grove's cell, and three tons with twenty cells. This conveniently arranged magnet, after being used for dia-magnetic experiments, may be employed for showing the attractive force of the great electro-magnet. It is attached to a lever, which turns it over; and, when suspended with the poles downwards, it is connected with a compound-lever arrangement, on the same principle as railway weighing-machines, and the weights used are one quarter, one half, and one hundredweight.

The writer well remembers the late Prince Consort, on the occasion of one of his private visits to the Polytechnic, putting a question to him as to the rate at which the electro-magnetic power increased or decreased with the distance from the great electro-magnet belonging to the Polytechnic. The attractive force diminishes enormously. Thus, in a paper read by Mr. Robert Hunt before the Institution of Civil Engineers, the following instructive diagram was exhibited:

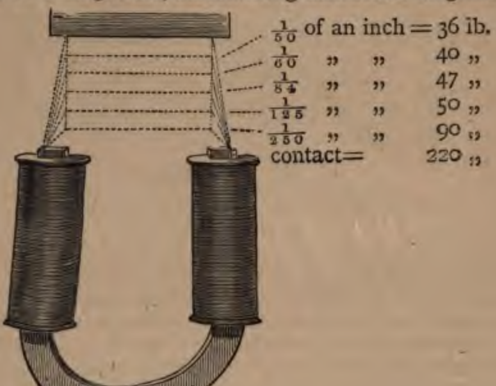


FIG. 32.

It is shown that, whilst *contact* gave a power of 220 lb., at a distance of $\frac{1}{50}$ an inch the attractive force diminished to 36 lb.

adhere to it as long as the current passes. If the wire is coiled upwards round a glass tube from left to right, it is called a dextrorsal helix; and if coiled downwards, and in the same direction, it is termed a sinistrorsal helix.

A piece of steel placed inside such a helix, conveying the voltaic current, is soon magnetized. If the same coil is used to convey the charge from a Leyden battery of 6 ft. surface, a piece of steel is instantly magnetized. Electricians had missed this form of the experiment until Œrsted's discovery.

If a bar magnet be held so that it is horizontal, and the north pole directed to the vertical portion of the rectangular wire, so supported that whilst conveying the electric current it moves freely round in a circle (Fig. 34), it will be found

FIG. 34.—*The Rectangular Wire freely suspended on a vertical Standard.*

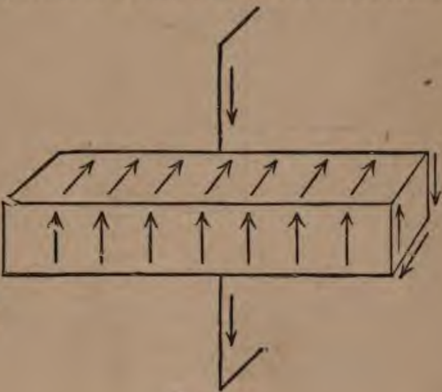


FIG. 35.

that, if the upright portion of the wire is conveying the current from below upwards, it is repelled, but attracted if the south pole is substituted; and thus, by the dexterous substitution of one pole for another in presenting the bar magnet to the rectangular wire, it may be caused to rotate.

Polarity is shown by the sides of the wire, whereas in steel magnets it is discoverable at the ends.

The same attraction and repulsion occurs if another electrified wire is brought towards the suspended rectangular wire whilst conveying the electrical current.

Fig. 35 is a good illustration of the direction of the current circulating around each section of a magnet everywhere in the same direction, viz., from top to bottom in the face that is turned towards the moving wire, and from bottom to top in that which is opposite to it. The sum of these directions amounts to a current.

A similar result is obtained when a horizontal wire is directed to a magnet suspended vertically. The magnetic currents circulating around the magnet are again shown by arrows. A magnet may, therefore, says De la Rive, be considered as formed by an association of electric currents, all circulating in the same direction around its surface, and all situated in planes parallel to each other, and perpendicular to the axis of the magnet. It is this hypothesis of Ampère of the constitution of magnets, shown in Figs. 35 and 36 and which

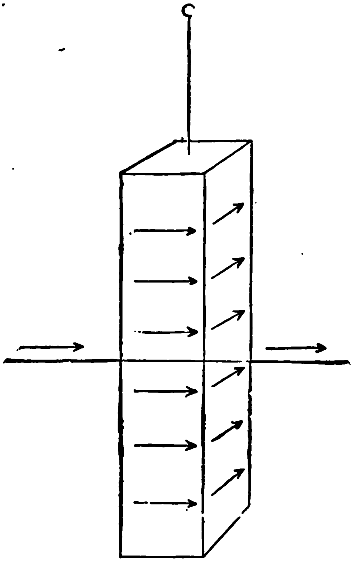


FIG. 36.—*Magnet suspended in a perpendicular line, the Current flowing horizontally.*

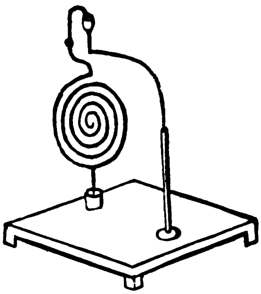


FIG. 37.

explains Œrsted's original experiment, and also all those that relate to the deviation. In order to confirm the hypothesis to which he had been led, of the nature of magnetism, Ampère endeavoured to arrange electric currents in the same manner as he had conceived they were naturally arranged in a magnet.

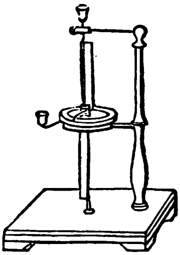


FIG. 38.—*Magnet revolving around Wire conveying the Current.*

Thus a flat spiral coil of wire (Fig. 37), nicely supported and resting on points, and perfectly mobile, takes a position perpendicular to the magnetic meridian. By reversing the experiment, and causing the wire to be fixed, and the magnet

to revolve around it (Fig. 38), further proof was obtained by Faraday of the mutual relations between magnets and wires conveying the voltaic current. In this case we have the revolution of one pole of a magnet about a vertical wire transmitting a rectilinear current. The direction of rotation is reversed each time the direction of the current is reversed.

Or the experiment may be again modified and reversed by supporting (as with the apparatus made so nicely by Messrs. Elliott) two helices or coils of copper which are made to convey the voltaic current, and rotate in opposite directions around the poles of the horse-shoe magnet, as shown in Fig. 39.

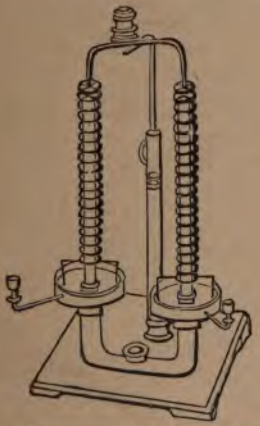


FIG. 39.—*Contrary Rotation of two helical Coiled Wires around the Poles of a Magnet.*

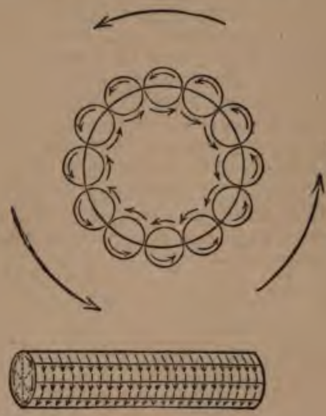


FIG. 40.

This apparatus is usually called Ritchie's spirals. De la Rive says Ampère succeeded in overcoming all objections to his theory, and established it on such a solid basis that it is at the present time generally admitted. He set out from the principle that the electric currents to which, according to his view, magnets owe their properties are molecular, that is, that they circulate around each particle. These electric currents pre-exist in all magnetic bodies even although they have not been magnetized, only they are arranged in an irregular manner, so that they neutralize each other. Magnetization is the operation by which a common direction is impressed upon them; whence it follows that the series of the exterior portion of the molecular currents, which are all moving in the same direction, constitutes a finished current around the magnet, whilst the interior portions are neutralized by the exterior ones, moving in the contrary direction, of the following molecular stratum.

Fig. 40 represents the section of a cylinder magnet and the magnet itself. The direction impressed upon the currents by magnetization is maintained in bodies that are endued will coercitive force, and ceases in others, such as soft iron, as soon as the force that determined it ceases, because then all the *molecular currents, being* free to obey their mutual action, take the relative *position that produces* equilibrium, or the neutralization of every exterior effect.

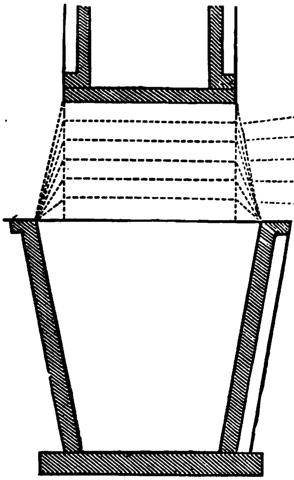
To Faraday is due the credit of realising the idea that the mutual reaction of magnets or wires conveying electrical currents, and *vice versâ*, should produce rotation; and he was the first to cause a wire conveying a current to revolve around a magnet, and the latter to rotate about a wire through which the voltaic current is passing.

These original and philosophical experiments have been extended to larger apparatus, and various attempts have been made to use the electro-magnetic rotation successfully: Dal Negro, 1832; Professor Botto and Professor Jacobi in 1835; Mr. Thomas Davenport, of the United States, in 1837; and Mr. Taylor in 1839.

Davidson, in 1837, placed an electro-magnetic locomotive on the Edinburgh and Glasgow Railway. The carriage was 16 ft. long and 6 ft. broad, and weighed about 5 tons, with all the arrangements; but, when put in motion, a speed of only 4 miles per hour could be obtained.

Professor Page constructed an electro-magnetic engine which created much interest at the time, and he calculated that the consumption of 3 lb. of zinc per diem was equal to one horse power. Page's engine was followed by those of Talbot and Wheatstone.

Mr. Hjörth exhibited in London an engine which found many admirers. The attractive force of Hjörth's machine is thus given by Mr. Hart, from whose valuable paper the above historical details are taken:



5 inches	72 lb.
4 ”	80 ”
3 ”	88 ”
$2\frac{1}{4}$ ”	124 ”
$1\frac{1}{2}$ ”	140 ”
1 ”	160 ”

FIG. 41.—*Hjörth's Principle.*

but, like the rest, it was abandoned.

Dr. Botto states that 45 lb. of zinc consumed in a Grove's battery are sufficient to work a one-horse power electro-magnetic engine for twenty-four hours.

Mr. J. P. Joule calculates that the same result would have been obtained by the consumption of 75 lb. of zinc in a Daniell's battery. Mr. Joule and Dr. Scoresby thus sum up a series of experimental results:—"Upon the whole,

we feel ourselves justified in fixing the maximum available duty of an electro-magnetic engine, worked by a Daniell's battery, at 8c lb. raised one foot high for each grain of zinc consumed. This is about one-half of the theoretical maximum duty. In the Cornish engines doing the best duty, one grain of coal raised 143 lb. one foot high. Zinc i. worth about £35 per ton, and engine coal is worth less than £1 per ton, delivered in London. Comment upon this is unnecessary.

The fact is, an electro-magnetic engine is a very pretty toy, and can be used, like Mr. Apps's half-horse power engine (Fig. 29, p. 22), to turn a small lathe, or propel a small boat, or turn whirling tables or other apparatus on the lecture-table, *i.e.*, where the cost of zinc and acids from the battery is of no consequence. Mr. Apps furnishes the following particulars of the above named electro-magnetic engine:

"Weight 80 lb. When driven to 400 revolutions per minute by 20 cells Grove (platina 6 in. × 3 in.), a half-horse power is obtained. It will drive with equal facility in either direction, or, on reversing the current by the double commutator, the magnetic power produced is opposite to the momentum previously acquired (acting like a friction-brake); the direction of rotation is reversed, and in about three seconds the former rate of speed is acquired.

"A very important point is gained in this machine. The current being gradually broken, the spark usually produced at the breaking of the contact is avoided. Besides this great advantage, the residual magnetism is destroyed, which alone in the old machines diminished their power by at least one quarter. The machine is well adapted to drive a lathe or the screw propeller of a small boat."

MAGNETO-ELECTRICITY.

INDUCTION BY CURRENT ELECTRICITY.

It has been noticed that a current of electricity elicits magnetism, and therefore it is not surprising that the effect should be reversible; but, simple as this may appear in theory, it was a long time before Faraday succeeded in overcoming the difficulties he encountered, and was enabled to relate his success in the "Philosophical Magazine, 1832, page 125.

The extremities of a helix or large hollow bobbin of wire were connected with the galvanometer needle, care being taken that the galvanometer should not be near enough to be affected by the magnet which Faraday used.

FIG. 42.—*Faraday's first Experiment.*

The movement of the bar magnet across the coils produced a current which affected the needle, and still better when, as in Fig. 42, the magnet was intruded into the axis or hollow of the bobbin or helix. Not only is the needle deflected when the magnet is insulated, but it is also moved in an opposite direction when the magnet is removed.

When two concentric helices, of course of insulated or covered wire, are arranged, the inner one being of thicker wire than the outer, and wound round an axis or core of soft iron, a very powerful secondary current is obtained in the outer coil when the inner core is magnetized. Such currents are called induced currents, and are always more powerful when soft iron forms the axis or core, because the iron, in acquiring or losing magnetism, produces a secondary current which occurs in the same direction as that induced by the inner coil or helix.

Here, then, is a distinct excitation or elimination of electricity by magnetism alone, and is called magnetic electric induction to distinguish it from *volta-electric induction, also* investigated by Faraday, and brought before the Royal

Society in 1831. In the latter experiments, two great coils of wires were wound together, metallic contact, of course, being prevented. One coil was connected with the galvanometer, and the other with the voltaic battery. The induced electricity in the second coil was suddenly produced like a wave, presenting a marked difference to the magneto-electric induction, which was much slower in its production. Here, then, are two modes of induction:

1. VOLTA-ELECTRIC INDUCTION;
2. MAGNETO-ELECTRIC INDUCTION.

The magneto-electric induction has been applied to the production of currents of electricity by Pixii—the first in Paris, 1832, followed by Saxton and E. M. Clarke.

Such instruments, in which a powerful compound-magnet, having rotating in front of its poles an armature or bobbin of fine wire (which may be varied to produce either quantity or intensity effects), elicits a current that can be made to illustrate physiological, mechanical, chemical, and ordinary electrical effects, are so fully described in every book on electricity that the writer prefers to pass to newer and more perfect arrangements.

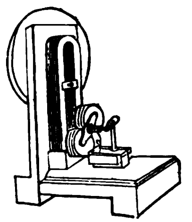


FIG. 43.

Magneto-electricity was applied and exhibited by Mr. Holmes in the Great Exhibition of 1862, and obtained from a machine of novel construction. At the same Exhibition, and also in Paris, 1867, the writer saw Nollet's machine as improved by Mr. van Malderen, who took great pains to show the writer the construction of his magneto-electric machine for light-giving purposes; and it was understood that, at a cost of £300, one of these machines, turned by a steam-engine, might supply the Polytechnic with the electric light at any time it was set in motion. The current passed to a Serrin's lamp, and certainly produced a most brilliant light.

In the article on the Telegraph, it will be noticed that Sir Charles Wheatstone uses a magneto-electrical machine of improved construction, instead of the voltaic battery. Wheatstone's exploder for military purposes generates its electricity in the same manner. There are many other modifications of induced currents, such as the experiments of Faraday, "On the Induction of a Current on itself," read before the Royal Society, 1835; and Dr. Henry's (College of New Jersey, Princeton) experiments (described in 1833) with flat coils of insulated copper ribbon and helices of fine covered copper wire, by which induced currents of the third, fourth, and fifth order could be obtained, by alternately arranging the insulated copper ribbons and the helices of fine wire.

In the "Proceedings of the Royal Society," No. 90, 1867, Sir Charles Wheatstone describes a most interesting series of experiments "On the Augmentation of the Power of a Magnet by the reaction thereon of Currents induced by the Magnet itself," as follows:

"The magneto-electric machines which have been hitherto described are actuated either by a permanent magnet or by an electro-magnet deriving its power from a rheomotor placed in the circuit of its coil. In the present note, I intend to show that an electro-magnet, if it possess at the commencement *the slightest polarity*, may become a powerful magnet by the *gradually augmenting currents* which itself originates.

"The following is a description of the form and dimensions of the electro-magnet I have employed. The construction, it will be seen, is the same as that of the electro-magnetic part of Mr. Wilde's machine.

"The core of the electro-magnet is formed of a plate of soft iron, 15 in. in length and ½ an inch in breadth, bent at the middle of its length into a horse-shoe form. Round it is coiled, in the direction of its breadth, 640 ft. of insulated copper wire $\frac{1}{12}$ of an inch in diameter. The armature, which is according to Siemens's ingenious construction, consists of a rotating cylinder of soft iron, 8½ in. in length, grooved at two opposite sides so as to allow the wire to be coiled upon it longitudinally; the length of the wire thus coiled is 80 ft., and its diameter is the same as that of the electro-magnet coil.

"When this electro-magnet is excited by any rheomotor the current from which is in a constant direction, during the rotation of the armature, currents are generated in its cell during each semi-revolution, which are alternately in opposite directions; these alternate currents may be transmitted unchanged to another part of the circuit, or by means of a rheotrope be converted to the same direction.

"If now, while the circuit of the armature remains completed, the rheomotor be removed from the electro-magnet, on causing the armature to revolve, however rapidly, it will be found by the interposition of a galvanometer, or any other test, that but very slight effects take place. Though these effects become stronger in proportion to the residual magnetism left in the electro-magnet from the previous action of a current, they never attain any considerable amount.

"But if the wires of the two circuits be so joined as to form a single circuit, in which the currents generated by the armature, after being changed to the same direction, act so as to increase the existing polarity of the electro-magnet, very different results will be obtained. The force required to move the machine will be far greater, showing a great increase of magnetic power in the horse-shoe; and the existence of an energetic current in the wire is shown by its action on a galvanometer, by its heating 4 in. of platinum wire ·0067 in diameter, by its making a powerful electro-magnet, by its decomposing water, and by other tests.

"The explanation of these effects is as follows:—The electro-magnet always retains a slight residual magnetism, and is therefore in the condition of a weak permanent magnet; the motion of the armature occasions feeble currents in alternate directions in the coils thereof, which, after being reduced to the same direction, pass into the coil of the electro-magnet in such manner as to increase the magnetism of the iron core; the magnet, having thus received an accession of strength, produces in its turn more energetic currents in the coil of the armature; and these alternate actions continue until a maximum is attained, depending on the rapidity of the motion and the capacity of the electro-magnet.

"If the two coils be connected in such manner that the rectified current from the coil of the armature passes into the coil of the electro-magnet in the direction which would impart a contrary magnetism to the iron core, no current is produced, and consequently there is no augmentation of magnetism.

"It is easy to prove that the residual magnetism of the electro-magnet is *the determining cause of* these powerful effects. For this purpose it is sufficient *to pass a current* from a voltaic battery, a magneto-electric machine, or *any other rheomotor, into* the coil of the electro-magnet in either direction,

and it will invariably be found that the direction of the current, however powerful it may eventually become, is in accordance with the polarity of the magnetism impressed on the iron core.

"If, instead of the currents in the coil of the rotating armature being reduced to the same uniform direction, they retain their alternations, no effects, or at most very small differential ones, are produced, as no accumulation of magnetism then takes place.

"I will now call attention to the fact that stronger effects are produced at the first moment of completing the combined circuit than afterwards. The machine having been put in motion, at the first moment of completing the circuit 4 in. of platina wire were made red hot; but immediately afterwards the glow disappeared, and only about one inch of the wire could be permanently kept at a red heat. This diminution of effect was accompanied by a great increase of the resistance of the machine. The cause of the momentary strong effect was, that the machine from its acquired momentum continued its motion for a few seconds, though it required a stronger force than could be applied to maintain that motion. Each time the circuit is broken and re-completed, the same effect recurs.

"On bringing the primary coil of an inductorium (Ruhmkorff's coil) into the circuit formed by connecting the coils of the electro-magnet and rotating armature, no spark occurs in the secondary coil. On account of the great resistance of the circuit, which now also includes the primary coil of the inductorium, the current is not in sufficient quantity to produce any noticeable inductive effect.

"A very remarkable increase of all the effects, accompanied by a diminution in the resistance of the machine, is observed when a cross wire is placed so as to divert a great portion of the current from the electro-magnet. The four inches of platinum wire, instead of flashing into redness and then disappearing, remains permanently ignited. The inductorium, which before gave no spark, now gave one a quarter of an inch in length; water was more abundantly decomposed; and all the other effects were similarly increased.

"I account for this augmentation of the effects in the following way:

"Though so much of the current is diverted from the electro-magnet by the cross wire, the magnetic effect still continues to accumulate, though not to so high a degree; but the current generated by the armature, passing through the short circuit formed by the armature branch and cross wire, experiences a far less resistance than if it had passed through the armature and electric-magnet branches; and though the electromotive force is less, the resistance having been rendered less in a much greater proportion, the resultant effect is greater.

"I must observe that a certain amount of resistance in the cross wire is necessary to produce the maximum effect. If the resistance be too small, the electro-magnet does not acquire sufficient magnetism; and if it be too great, though the magnetism becomes stronger, the increase of resistance more than counterbalances its effect.

"But the effects already described are far inferior to those obtained by causing them to take place in the cross wire itself. With the same application of force, 7 in. of platinum wire were made red hot, and sparks were elicited in the inductorium $2\frac{1}{2}$ in. in length.

"*The force of* two men was employed in these, as well as in the other *experiments.* When the interrupter of the primary coil was fixed, the machine

was much easier to move than when it acted. For when the interrupter acted, at each moment of interruption the cross wire being, as it were, removed, the whole of the current passed through the electro-magnet, and consequently a greater amount of magnetic energy was excited, while in the intervals during which the cross wire was complete the current passed mainly through the primary coil.

"The effects are much less influenced by a resistance in the electro-magnet branch than in either of the other branches.

"To reduce the length of the spark in the inductorium (the primary coil of which was placed in the cross wire) to $\frac{3}{4}$ of an inch, it required the resistance of $5\frac{1}{4}$ in. of the fine platinum wire in the cross wire, 5 in. in the armature branch, and 4 ft. in the electro-magnet branch.

"When there was no extra-resistance in either of the branches, the length of the cross wire being only about a few feet, the intensity of the current in the electro-magnet branch, compared with that in the cross wire, was as 1 : 60; and when the resistance of the primary coil of the inductorium was interposed in the cross wire, the relative intensities were as 1 : 42.

"In conclusion, I will mention that there is an evident analogy between the augmentation of the power of a weak magnet by means of an inductive action produced by itself, and that accumulation of power shown in the static electric machines of Holtz and others, which have recently excited considerable attention, in which a very small quantity of electricity directly excited is, by a series of inductive actions, augmented so as to equal, and even exceed, the effects of the most powerful machines of the ordinary construction."

Mr. Wilde's machine has been fully described in all the illustrated scientific papers, such as "The Engineer" and "The Mechanic's Magazine." The writer, therefore, proposes to give drawings of Mr. Ladd's improved magneto-electric machine, which he thus describes in the "Transactions of the Royal Society," No. 91, 1867:

"In June, 1864, I received from Mr. Wilde a small magneto-electric machine, consisting of a Siemens's armature and six magnets. This I endeavoured to improve upon, my object being to get a cheap machine for blasting with Abel's fusees. This was done by making one of circular magnets, and a Siemens's armature revolving directly between the poles, the armature forming part of the circle; with this I could send a very considerable power into an electro-magnet, &c. It was then suggested to me, by my assistant, that if the armature had two wires instead of one, the current from one being sent through a wire surrounding the magnets, their power would be augmented, and a considerable current might be obtained from the other wire available for external work; or there might be two armatures—one to exalt the power of the magnets, and the other made available for blasting or other purposes. Want of time prevented me carrying this out until now; but since the interesting papers of C. W. Siemens, F.R.S., and Professor Wheatstone, F.R.S., were read last month, I have carried out the idea as follows:—Two bars of soft iron, measuring $7\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in. $\times$ $\frac{1}{2}$ in., are each wound, round the centre portions, with about thirty yards of No. 10 copper wire; and shoes of soft iron are so attached at each end, that when the bars are placed one above the other there will be a space left between the opposite shoes, in which a Siemens's armature can rotate: on each of the armatures is wound about ten yards of No. 14 copper wire, cotton-covered. The current generated in one of the armatures is always in connexion with the electro-magnets; and the current from the second arma-

ture, being perfectly free, can be used for any purpose for which it may be required. The machine is altogether rudely constructed, and is only intended to illustrate the principle; but with this small machine three inches of platinum wire ·01 can be made incandescent."

Mr. Ladd now calls his improved machine, which it is hoped may be permanently erected some day at the Polytechnic as a convenient source of electricity for all purposes, the "Dynamo-Magnetic Machine" (Fig. 44).

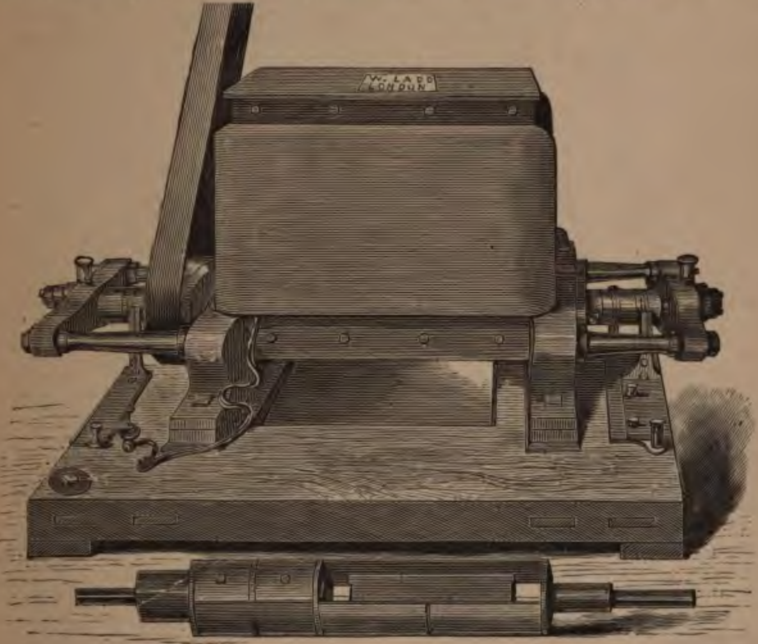


FIG. 44.

This machine was awarded a silver medal at the Paris Exhibition, 1867. Another form of the apparatus (Fig. 45), also constructed by Mr. Ladd, is that in which the two armatures are combined in one, and the coils are wound at right angles to each other.

The results obtained are simply regulated by the amount of mechanical force used to rotate the armatures; and thus indirectly coal, used as a means of exciting electricity, is made to generate steam, which produces force in the steam engine, and this ultimately turns the dynamo-magnetic machine; and thus *indirectly* coal generates an electric current, by which the electric light is obtained.

A convenient little magneto-electrical machine is made by Mr. Browning, for the purpose of giving shocks and for medical use. (Fig. 46.)

FIG. 45.

Directions for using the Instrument.—Take the hollow conductors A B off from the large studs on which they are placed; uncoil their metallic cords which are wound upon them, and insert the pins which are attached to the ends of these cords into the small holes which will be found in two upright brass studs at the back of the stand of the machine, marked C D in the diagram; then upon holding the hollow conductors, one in each hand, and turning the handle of the machine quickly, a strong electrical current will be felt.

A horizontal stud in front of the machine, projecting beyond the frame, serves to move an iron feeder before the ends of the large circular magnet. By shifting this feeder, the strength of the current given out by the machine can be regulated within any desirable limit. When the feeder is lifted up in front of the magnet, the current will be very feeble; when it is withdrawn ouite below the magnet, it will be very intense.

Two brass springs project from the brass studs C D; these springs should rest on the edge of a small wheel of ebonite and brass, known as a commutator. It sometimes happens that, from rough usage in carriage, these springs are bent, so that they no longer touch the edge of the wheel; in this case the current becomes greatly weakened, or altogether ceases; but the machine can be easily set right by carefully bending down the springs so that they again rest upon the edge of the wheel.

We now come to the last of the induction machines, sometimes called the *induction coil, the inductorium*, &c. In 1851, M. Ruhmkorff, a most clever *instrument maker in Paris*, made a coil which produced in the scientific world

FIG. 46.—*Browning's Magneto-Electrical Machine.*

of Paris and London a profound sensation of surprise and delight at the beautiful light-effects obtainable.

Mr. Hearder, of Plymouth, and Mr. Bentley subsequently made coils of great power; but to Mr. Ladd is due the merit of constructing a serviceable apparatus which would always produce the most reliable results. A very large coil, having a secondary coil of seven miles of wire, has long been used at the Polytechnic. It consists of the usual primary coil, wound round a faggot of iron wires; around this is the secondary coil, of the required number of miles in length. The condenser, composed of alternate sheets of tinfoil and well dried and varnished paper, is placed under the coil, and, by making and breaking contact with the primary by a convenient "contact-breaker," an enormous current is induced in the secondary, which produces the most brilliant results.

FIG. 47.—*Plücker's Tube.*

A Leyden jar or Leyden plate may be incessantly charged and discharged with a continuous roar. Paper is immediately set on fire when held between the poles. Tubes of glass are filled with various gases or liquids, or rather not filled according to the ordinary acceptation of the term, because they are *vacua*, the last gas which has been permitted to enter the tube alone representing the attenuated atmosphere through which the electric current passes.

The reader is referred to Dr. Noad's little book, entitled "The Inductorium," and published by Churchill for Mr. Ladd, for all the minute details connected with the primary coil, the secondary, the condenser, and the thousand-and-

one experiments which, like the "Arabian Nights' Entertainments," crowd upon the student, but which may all be performed with the apparatus described.

Amongst the most interesting experiments, that of Plücker deserves especial notice.

"Two aluminium rings are hermetically sealed into a glass tube, 4 or 5 in. long and about $1\frac{1}{2}$ in. in diameter; the air in the tube is then exhausted as perfectly as possible. On passing the discharge from the induction coil between the two rings, the tube becomes filled with a beautiful pale blue light.

FIG. 48.—*Plücker's Tube with Aluminium Wires.*

"If the small ring be made negative, and the tube placed between the poles of an electro-magnet, the moment the latter is excited the light arranges itself in the form of a broad arc between the rings.

FIG. 49.—*Gassiot's Cascade,*

The current passing into and out of a glass vessel placed in a vacuum.

"On rendering the electro-magnet passive, the arc disappears, the light in the tube re-assuming its different character; but, on re-exciting the magnet,

the arc re-appears. If, instead of two rings, the terminals in the tube are two aluminium wires, as shown in Fig. 48, the long wire being made positive and the short wire negative, the arc produced is very broad and brilliant."

It must be apparent from the preceding figures that the stratification noticeable in all experiments of this type is a special object of interest, to which M. Gassiot, the generous and large-hearted friend of science, has paid particular attention.

Speaking of Geissler's (of Bonn) tubes,—one of the prettiest arrangements the writer has seen is that of Mr. Apps, and shown in the next figure.

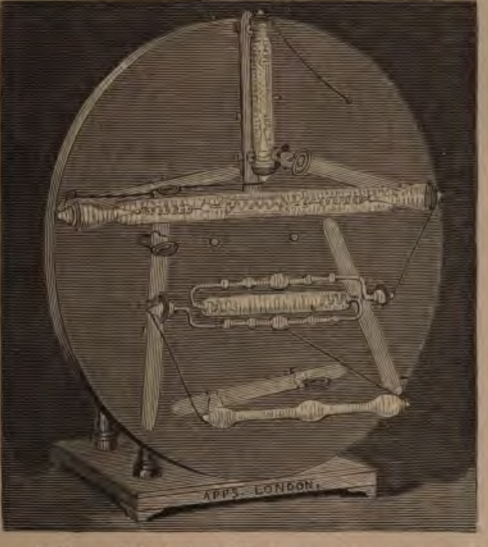


FIG. 50.—*Front View of Geissler's Tubes, arranged on a disc of blackened Mahogany.*

The back view exhibits the use of the electro-magnetic engine for rotating or reversing the disc. (Fig. 51.)

The electro-magnetic engine, in a convenient and handsome form, well adapted to rotate the vacuum tubes, is attached to the black polished disc, and arranged so as to turn in either direction: the speed can be easily regulated. The discharge from the coil passes through the entire series of tubes.

Amongst the remarkable effects produced by the induction coil, there are none more interesting than the generation of ozone by the "ozone tube," which is thus described by Dr. Noad, and made by Mr. Ladd. (Fig. 52.)

It consists of a glass tube, about the size of an ordinary test tube, coated with tinfoil or, still better, silvered, and enclosed in an outer tube lined outside with tinfoil. The two tubes are sealed together at the neck of the outer

FIG. 51.

one, and so adjusted that the space between them shall be as narrow as possible.

At the projecting end of the inner tube is a brass button, which is connected by a spring with one of the binding-screws on the frame of the apparatus, which screw is to be connected with one of the terminals of the secondary coil of an inductorium, and the other with another binding-screw in metallic communication with the coating of the exterior tube.

The apparatus is, in fact, a sort of slit Leyden jar; and air or oxygen, admitted through the lateral tube, becomes during its passage through the apparatus powerfully ozonized.

The air may be driven through by means of a bladder or india-rubber bag, or drawn through with an aspirator.

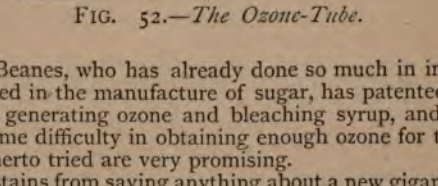


FIG. 52.—*The Ozone-Tube.*

Mr. Edward Beanes, who has already done so much in improving certain processes required in the manufacture of sugar, has patented the application of apparatus for generating ozone and bleaching syrup, and, although there appears to be some difficulty in obtaining enough ozone for this purpose, the experiments hitherto tried are very promising.

The writer abstains from saying anything about a new gigantic coil, building for the Polytechnic by Mr. Apps. Like David with his armour, he has not proved it: had he done so, this article would have contained an account of the Mammoth Induction Coil.

THERMO-ELECTRICITY.

Electricity produces magnetism, heat, light, mechanical and chemical effects. It is not opposed to the harmony of created forces that heat should produce electricity.

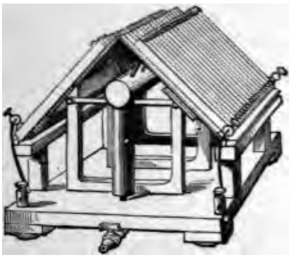


FIG. 53.—*Marcus's Thermo-Electric Battery, made by Mr. Ladd.*

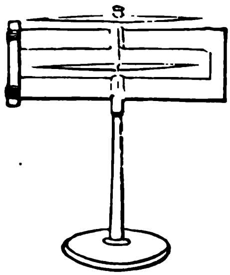


FIG. 54.

The above battery (Fig. 53), consists of thirty-six elements; the negative bars, which are 6 in. long, being composed of 12 parts of antimony, 5 of zinc, and 1 of bismuth; and the positive bars, which are 7 in. long, of copper 10 parts, zinc 6 parts, and nickel 6 parts. The bars are ranged on a frame in the slanting position shown in the figure, and were facetiously referred to by a writer in "Punch" as a "chestnut roaster," the positive bar of the first pair being metallically connected with the negative of the second, and the two extreme bars connected with binding-screws which form the terminals of the battery. The upper ends of the bars are heated by a series of Bunsen's burners, the flames of which can be easily regulated.

This battery at the Polytechnic, under the charge of Mr. J. L. King, decomposed water, of course very feebly; it gave small sparks between iron points without the assistance of a coil, and enabled an electro-magnet to support a considerable weight, and, when connected with an induction coil, gave sparks which were very marked in their character and length.

We have now to ask how this apparatus, in which heat takes the place of friction, chemical action, or magnetism, elicits electric force.

Seebeck's apparatus, a rectangular figure, made of bismuth and antimony, with an astatic magnetic needle supported inside, well exhibits the thermo-electric action; and, directly one of the angles is gently heated by a spirit flame, the needle, like that of the galvanometer with the voltaic circuit, is deflected. (Fig. 54.)

Pouillet's thermo-electric apparatus (made by Elliott), and already figured in Wheatstone's paper on the Rheostat (p. 127), consisting of a short cylindrical bar of *bismuth, bent twice* at right angles, with soldered copper wires attached *to the ends, communicating* with an ingenious contrivance on the stand for

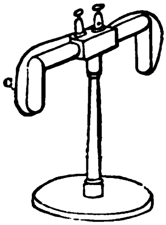


FIG. 55.—*Pouillet Thermo-Electric Circle.*

completing the electric circuit in any direction, is another and most perfect arrangement for showing currents of electricity obtainable by the exciter, "heat." (Fig. 55.)

On the second or third page of this work, in the article on Light, Melloni's small and compact composite "thermo-electric pile" is specially alluded to.

When the writer was a student, thirty years ago, he well remembers trying experiments with this beautiful contrivance for showing minute disturbances of heat; and, at that time, it had the reputation of being delicate enough to show the heat of the body of a "fly or a blue-bottle." Exaggeration apart, its

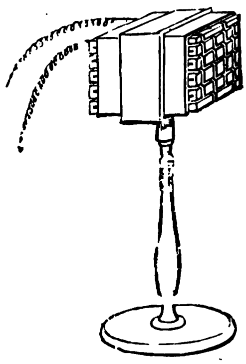


FIG. 56.—*Melloni's Thermo-Electric Pile or Battery.*

power to show the slightest heat-wave disturbance has never been equalled by any other apparatus. It consists of a series of pairs of very slender bars of antimony and bismuth soldered alternately together, and arranged parallel side by side, so that all the soldered pairs are at one end, and all the solders not pairs at the other. This apparatus, mounted in a brass tube and placed on a stand, is now the special attendant at all lectures in which the dynamical theory of heat is taught. (Fig. 56.)

The late Mr. Francis Watkins, the predecessor of the Messrs. Elliott, paid particular attention to this subject, and constructed a "Thermo-Electric Combinator." Eighteen pairs of bismuth and antimony, united alternately by

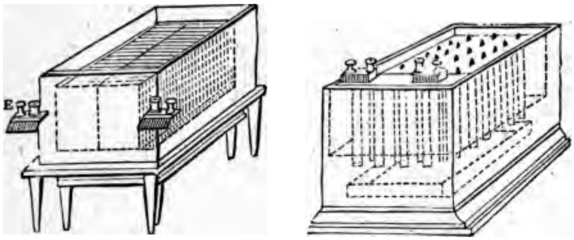


FIG. 57.—*Van der Voort's Thermo-Electric Battery.*

solder top and bottom, and fixed in a mahogany box by plaster of paris, leave the two extremities to be acted upon, the one by heat and heated iron or boiling oil, and the other by cold—some ice or a freezing mixture. All the common effects of an electric current, such as the spark, &c., can be shown with this contrivance.

Thus the corelation of forces is complete, and Light, Heat, Electricity, and Magnetism resolve themselves into each other, and represent probably a series of waves, every one of which is different from the other in the phases of its vibrations and resultant form.

Portrait and Autograph of Sir Charles Wheatstone.

WHEATSTONE'S TELEGRAPHS.

The limits of this article will not permit of any lengthened history of all the clever inventions either proposed or carried out by the various scientific men who have contributed to our knowledge of the science of telegraphy.

Whatever amount of credit may be accorded to others, there can be but *one opinion* respecting the merits of a living philosopher, whose portrait graces *the head of this chapter.* Foreigners are usually very frank and honest in *their expression of* the amount of merit due to their contemporaries in other

countries. The jury of the French Exhibition of 1855 thus report upon Wheatstone:

"La transmission de l'électricité entre les pays séparés par la mer n'a pu s'effectuer qu'au moyen de cables particuliers unissant entre élles les stations télégraphiques. Mais combien de travaux n'a-t-il pas fallu pour atteindre ce but; et même maintenant que la question est résolue, on ne peut sans admiration penser que la transmission des dépêches télégraphiques est aussi facile à l'aide des cables sous-marins qu'au moyen des fils isolés et tendus dans l'air. C'est par l'emploi de ces cables que l'on a pu mettre en relation télégraphique la France et l'Angleterre, la Crimée et les provinces Danubiennes, les pays enfin dans lesquels ces principes ont été appliqués, et peut-être bientôt l'Europe et l'Amérique. Le Jury a voté une mention très-honorable pour M. Wheatstone (Royaume Uni), membre du Jury de la IX[e] classe, pour avoir conçu l'idée première et pour avoir proposé, en 1840, un moyen de résoudre la question; il accorde la même distinction à M. Brett (Royaume Uni), sous la direction duquel a été placé un conducteur au travers de la Manche, entre Douvres et Calais, et qui a montré ainsi que le succès était possible. Le Jury décerne également une mention très-honorable à M. Crampton (Royaume Uni), membre du Jury de la V[e] classe, auquel revient l'honneur d'avoir réalisé cette immense application, en unissant définitivement, en 1851, par un cable sous-marin, la France et l'Angleterre."

Another very distinguished foreigner, A. De la Rive, thus speaks of Wheatstone in his "Treatise on Electricity:"

"The philosopher who was the first to contribute by his labours, as ingenious as they were persevering, in giving to electric telegraphy the practical character that it now possesses is, without any doubt, Mr. Wheatstone. This illustrious philosopher was led to this beautiful result by the researches that he had made in 1834 upon the velocity of electricity—researches in which he had employed insulated wires of several miles in length, and which had demonstrated to him the possibility of making voltaic and magneto-electric currents to pass through circuits of this length."

The following is the order of the inventions made by Sir Charles Wheatstone:

The 5-needle telegraph, 1837.
The alphabet-dial telegraph, 1840.
The type-printing telegraph, 1841.
The new magnetic alphabetic-dial telegraph, 1858-60.
The fast-speed automatic telegraph, 1858—1867.

Sir Charles Wheatstone, in addition to the other honours he has lately received, has just been elected to replace Faraday as one of the twelve corresponding members of the "Società Italiana delle Scienze, detta dei XL.," and has also received their first gold medal, instituted during the present year by the late Minister of Public Instruction, Signor Matteucci, to honour the most important discoveries in physical science.

The president, in his address, says:

"I will not here pass in review the various memoirs in physics which you have published in the 'Philosophical Transactions,' since all carry the impression of the inventive genius which ever distinguishes all that you have done. I cannot, however, refrain from calling to mind that to you we owe the discovery of the method, as ingenious as it is original, for measuring the velocity of electric currents and the duration of the spark.

"The applications of the principle of the rotating mirror are so important and so various that this discovery must be considered as one of those which have most contributed in these latter times to the progress of experimental physics.

"Not less ingenious was the invention of the stereoscope and of the modes by which binocular vision is effected, which enable us to obtain the perception of relief from the simultaneous observation of two plane images.

"Also the memoir on the measure of electric currents, and on all the questions which relate thereto and to the laws of Ohm, has powerfully contributed to spread among physicists the knowledge of those facts and the mode of measuring them with an accuracy and simplicity which before we did not possess.

"All physicists know how many researches have since been undertaken with your rheostat (see p. 126) and with the so-called Wheatstone's bridge, and how usefully these instruments have been applied to the measure of electric currents, of the resistance of circuits, and of electro-motive forces.

"And here it would be impossible to leave out of view that to you we principally owe the practical invention and the true realization of the electric telegraph.

"Finally, I would call to mind your recent researches on the augmentation of the force of a magnet by the reaction which its own induced currents exert upon it.

"All these great acquisitions, procured by you, to physical science render you well worthy of this distinction from the Italian Society of Sciences.

"Preserve yourself in health and activity, and your country and all your admirers and friends are certain to find, in the discoveries still to be added while you continue to work, some compensation for that immense and irreparable loss which natural philosophy has received by the death of Faraday."

In addition to the memoirs by Sir Charles Wheatstone, alluded to by Signor Matteucci, the following may be specially noticed:

"On the Acoustic Figures of Vibrating Surfaces," published in the "Philosophical Transactions" for 1832. In this memoir, which gained for Sir Charles his admission into the Royal Society, the author gave for the first time the laws of formation of the varied and beautiful figures discovered by Chladni. Attention has recently been revived to this subject by König and others on the Continent.

"On the Transmission of Sound through Solid Conductors" ("Journal of the Royal Institution," 1828). This memoir describes the means discovered by the author of transmitting musical performances to distant places.

"On the Prismatic Analysis of Electric Light" (British Association, 1832). By these experiments Sir Charles proved for the first time that the spectrum of the electric spark from different metals presented each a definite series of lines differing in colour and position from each other, and that these appearances afforded the means of distinguishing the smallest fragment of one metal from that of another. This investigation was one of the earliest starting-points of an entire new branch of physical science, in which there are now many distinguished workers.

"On the Polar Clock" (British Association, 1849). This is an optical instrument which indicates the time by means of the changes in the plane of polarization of the blue light of the sky in the direction of the pole. It is founded on the discoveries of Arago and Quetelet; and Arago states that

"l'honneur de la construction de l'horloge polaire, je la reconnais avec empressement et sans réserve, revient exclusivement à M. Wheatstone."

It would carry us beyond our limits to enumerate the various inventions relating to the electric telegraph and other applications of electricity which have emanated from Sir Charles. We will mention two only.

We owe to him, in addition to his former inventions relating to the electric telegraph, the alphabetical-dial telegraph, working without any clockwork power, and in which a magneto-electric machine supplies the place of a voltaic battery. These instruments were first introduced on the Paris and Versailles Railway in 1846, and, with the improvements which the inventor has since made, have been employed to a great extent throughout the kingdom by the Universal Private Telegraph Company in furnishing telegraphic communication between public offices and private establishments, to which purposes, from their facility of manipulation and constancy of action, they are admirably adapted.

A more recent invention is his fast-speed telegraph, in which the messages, previously prepared on strips of paper by manipulations as easy as those for sending an ordinary message, are, by passing through a very small machine constructed on somewhat the principle of a Jacquard loom, made to print the messages at the remote station in the ordinary telegraphic characters, with a rapidity and distinctness unattainable by the hand of an operator. The invention of these instruments dates from 1858; but they have only, with recent improvements, been practically introduced, by the Electric Telegraph Company, during the last year. Since June last these instruments have been in constant action for the ordinary business of the establishment between London and Newcastle, printing from sixty to a hundred and ten words per minute. The result has been so successful that the company have just resolved to adopt them on other leading lines of communication.

In the report of the Paris Exhibition of 1855, honourable mention was awarded to Sir Charles, he being *hors de concours*, for having been the first to conceive the idea, and for having proposed, in 1840, a means of resolving the question, of a submarine telegraph between Dover and Calais.

It may be mentioned in reference to an eminent philosopher, Sir David Brewster (whose loss we have had to deplore), that one of the last acts of his life was to nominate Wheatstone for election as an honorary member of the Royal Society of Edinburgh, thus falsifying the couplet of Dryden, who says,

> "Forgiveness to the injured does belong;
> But they ne'er pardon who have done the wrong."

In 1868 Wheatstone received the honour of knighthood at the hands of his gracious sovereign, and this same year of grace the Royal Society have awarded to him their highest distinction, viz., the Copley medal.

> "This is the state of man: to-day he puts forth
> The tender leaves of hope; to-morrow, blossoms
> And bears his blushing honours thick upon him."

In concluding this brief notice of the laborious and useful life of Wheatstone, we may, in common with all his friends and admirers, be permitted to hope that he may pass the evening of his days in peace and in the enjoyment of health, and that he will give to the world, in the calmness of matured age, a *monograph of the "Labours of his Life."*

In every book devoted to the consideration of electric telegraph instruments

we find illustrations and descriptions of Cooke and Wheatstone's earlier inventions of the single and double needle telegraph. We will, therefore, commence at the year 1840, when he constructed the alphabet-dial telegraph, which the writer has always found to be one of the best forms for teaching and demonstrating the broad principles upon which motion is developed by a current thrown alternately from one electro-magnet to another. Such is the construction of the telegraph, the dial of which is shown at Fig. 58.

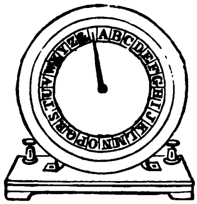


FIG. 58.—*Wheatstone's first Alphabet-Dial Telegraph* (1840).

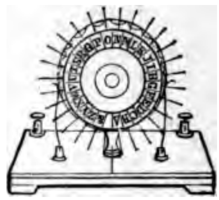


FIG. 59.—*Wheatstone's Communicator* (1840).

It consists of a circular dial, on which the letters of the alphabet are painted in black letters on a white ground. The mechanism is very simple. Two electro-magnets, with feeders and long arms, strike alternately the pallets; these take up at each blow one tooth of a wheel or escapement, and every time a tooth is taken up the hand on the dial moves forward one letter. To make the letters on the dial coincide with the letters of the sender of the message, another instrument is required, called the "communicator." (Fig. 59.)

This consists of a wheel, upon the circumference of which are thirty alternations of brass and ivory corresponding to the letters of the alphabet, &c., with which also this instrument is provided. There are two springs, one on each side, which communicate alternately with the communicator and through that to the battery and wires of the dial telegraph. When the communicator is turned round one letter, the hand or the dial moves one letter; and, if the instruments are very carefully made, they answer remarkably well.

Wheatstone, however, found that they sometimes missed a tooth in the escapement, and, of course, one letter being gone, the message afterwards might be very chaotic, particularly when a number of words in rapid succession had to be forwarded. This system was, however, at the time adopted on some of the continental lines.

Passing by the type-printing telegraph of 1841, we now come to the new magnetic alphabetic-dial telegraph of 1858 and 1860.

The reader will be able to understand the construction better by reading and examining the annexed description and diagrams than if a minute description of the above instrument (Fig. 60) were given at once. It is, perhaps, unnecessary to remark that these instruments are in daily use by the Universal Private Telegraph Company.

Instructions for connecting-up the Instruments.—The instruments (communicator, indicator, and alarum) at each station should first be placed in short circuit in the following manner (Fig. 61):

Place short wires upon the two upper terminals, *a b*, at the back of the indi-

FIG. 60.—*Wheatstone's new Magnetic Alphabetic-Dial Telegraph.*

cator, and connect them with *c* and *d* respectively, the switch, *x*, being turned to point to the letter T—Telegraph. The handle, *z*, of the communicator is then to be turned steadily at a rate of about a hundred and twenty revolutions per minute, and the index or pointer passed from + to + on the dial by

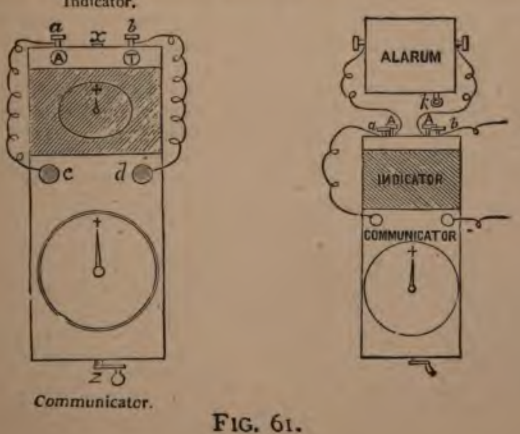


FIG. 61.

depressing the finger-key opposite the full stop (.) and the key opposite the + immediately afterwards. If the index of both communicator and indicator correspond, the connections will be right; but should the hand of the indicator be either in advance or behind the + one space, the connecting wires must be reversed.

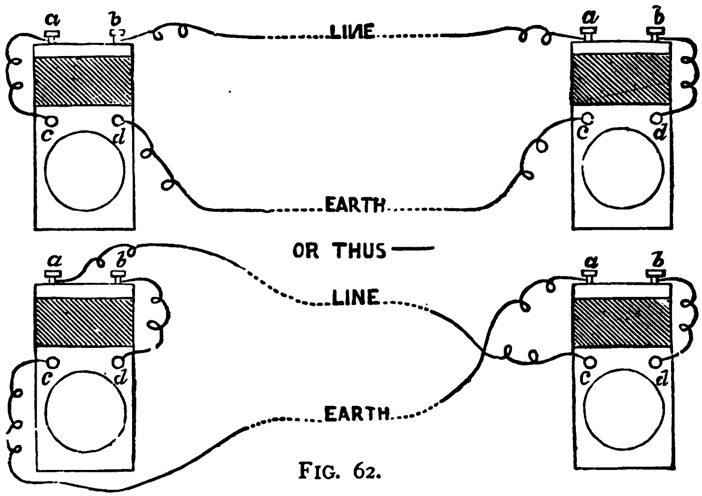


FIG. 62.

a being now joined up to *d*, and *b* to *c*, the instruments will be found to correspond in the revolution of their pointers round the dials. The line wire may now be connected to the instruments by removing one of the short wires at each station, and substituting the line wire and earth wire, as shown at *a b* and *c d*. The same signal of passing the pointer from + to + is now to be sent from station to station, and if the index at the other station falls either one in advance or behind, the position of the line and earth wires at one station only must be reversed.

The hand of the indicator may be reset by gently moving the small button under the face backward and forward between the thumb and finger.

When more than two stations require to be connected up in the same circuit, the above rules are to be observed with reference to the signals from + to + at each successive station, the connections appearing thus (Fig. 63)—

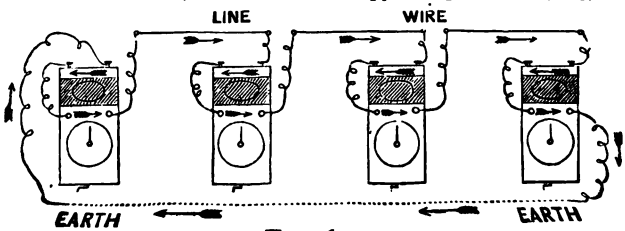


FIG. 63.

When several stations are in the same circuit, it will often be found convenient to introduce the switch, enabling the operator to send up and down the line in either direction, without interrupting the communication of those stations situated in an opposite direction to that in which he is speaking. The

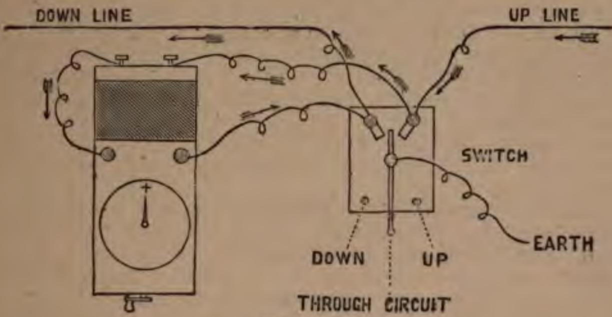


FIG. 64.

manner of connection will be seen by reference to the drawing. This arrangement will enable several stations to communicate with each other at the same time.

a———*b*———*c*———*d*———*e*———*f*———*g*———*h*

For instance, while *a* is speaking to *b*, *c* can talk to *d*, *e* with *f*, and so on. This system requires that each station has its own signal or preface for calling attention, and that when no station is called either up or down the line, the handle of the switch remains on the *through circuit*, as shown in the diagram. The switch is generally adapted to the peculiar requirements of the line.

When alarums or bells are used to call attention, they must be placed in circuit by connecting their binding-screws to the two lower binding-screws at the back of the indicator. The alarum may be placed at any distance from the instrument, in the most convenient position for calling attention. The switch, *x*, of the indicator should point to A, alarum, when no messages are being sent, but be turned to T when operations begin.

Instructions for working the Telegraphs.—The following summary of rules for working the telegraph may be advantageously introduced here:

1. The handle in front of the instrument (Fig. 60), which causes the armature of the magnet to rotate, must be kept in *continuous* motion by one hand, while the fingers of the other are employed to manipulate the stops or keys. Care must be taken not to intermit the motion until the end of the message.

2. A key need not be continuously pressed down; it will suffice merely to touch it; but another key must not be pressed down until the index or pointer has arrived at the letter previously indicated.

3. The same key cannot be pressed twice down in succession; to repeat a letter it is necessary to touch the preceding key, and, without waiting for the arrival of the index, to touch again the proper key.

4. Before commencing to send a message, the index of all the instruments must point to +. To bring the telegraph to this position when out, the small

pin or button on the face of the telegraph must be moved alternately backwards and forwards between the finger and thumb until the index stands at +.

5. If by inadvertence the index of the communicator has been left at a letter, it must be brought to the cross before the telegraph is adjusted.

6. The pointer of the alarum must invariably, when the instrument is not in use, be turned to the letter A.

7. To call attention for the purpose of sending a message, first turn your own alarum off, then rotate the handle of the communicator and let the needle pass from + to +. This will ring the bell at the other end. Wait an interval of time sufficient to allow of reply. If no reply, continue to call in the same manner.

8. Receiver will notify his attention by repeating the signal.

9. The receiver will then turn off his alarum, by passing the pointer from letter A to T.

10. A short time must be allowed the receiver before sending, to enable him to put his indicator in accord with his transmitter, if it be wrong.

11. At the end of each word the needle to be brought to the +.

12. Should the receiver not understand, he will send the letter R for repeat, prior to giving +. The sender will then repeat the last word.

13. Every initial letter or part of a word used for abbreviation must be followed by the full stop, and the full stop must be given at the end of each sentence.

14. At the end of message, needle to be turned from + to + twice.

15. Receiver to repeat this double revolution.

16. If by accident the needle of the indicator becomes misplaced, so as to render a message unintelligible, the receiver must break in by pressing down several keys in succession. The sender will immediately stay sending. Both receiver and sender will then set needles at +, and receiver will give repeat, R.

17. To signify figures, use the semicolon, and then the +, before and after them.

Instructions for keeping the Instruments in order.—When the telegraph is in operation, the handle of the communicator should be turned at a uniform rate of 120 revolutions per minute, and the finger-keys should not be depressed when the handle is at rest.

The working parts and bearings of the communicator will require occasionally to be oiled with good watch-oil, procured from any respectable watchmaker. If the oil is good, and the telegraph moderately used, the instrument will work eight or ten months without touching; but, when in constant use, it is desirable to apply a little oil regularly every two months. Access for this purpose may be obtained to the interior of the communicator by unscrewing the bottom of the communicator. The various parts to be oiled are shown in the annexed diagram at *a*, *b*, *c*, *d*; and by dipping the point of a penknife into the oil, it may be neatly applied in small quantities where desired.

If the centre, *b*, has become worn by constant revolution, and causing the armature, *e*, to touch the iron prolongations of the magnet, the handle will work stiffly or stop altogether. This may be remedied by tightening slightly the screw, *g* (Fig. 65), with a pair of small pliers, or other means sufficient to free the armature from contact with the poles of the magnet.

After long use, the watch-chain, which runs round the rollers on the lower plate, for the purpose of mechanically raising each key, after it has been depressed by the hand, may become too slack; this is remedied by slightly

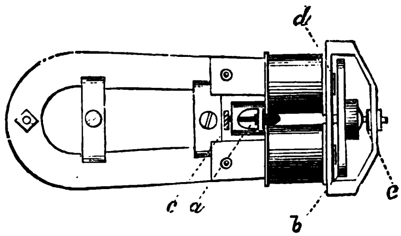


FIG. 65.

tightening the screw, A, attached to a lever carrying an extra roller, care being taken to leave sufficient slack in the chain to allow of one key always remaining depressed, as shown at B (Fig. 66).

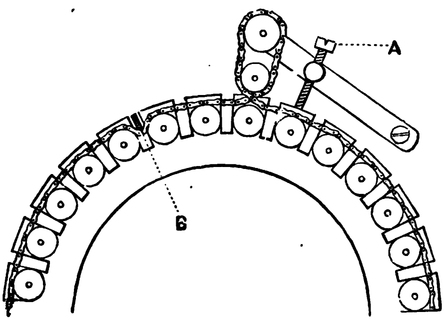


FIG. 66.

If it becomes necessary to take the communicator to pieces (this operation had always better be performed by a clock or watch maker, or other experienced person), the bottom of the case must be taken off first, and the little ivory number-plate in front of the instrument pushed out from the inside. This will enable the position of the wheel and pinion to be marked through the hole of the number-plate, by making a scratch (Fig. 67), as at *x*, across both, care being taken in putting together that the marked parts of the wheels are placed as before. The magnet may then be taken out, having previously unscrewed the wires leading from the coils. The brass casing which covers the upper portion of the mechanism is now to be unscrewed, and the ring with the glass, which is only sprung on, removed; then the dial card and plate. Unscrew *the four pillars below,* and, after the whole frame has been taken off the *wooden case,* all may be taken to pieces. It will be necessary to mark the

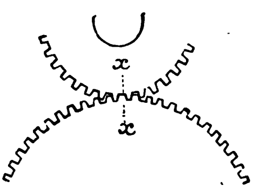


FIG. 67.

position of the two wheels, *h* and *i*, by a scratch across both, before taking that portion asunder. Oil must be put to the teeth of the wheel *k*, and also to *n*, *m*, *o*, and *p* (Fig. 68.)

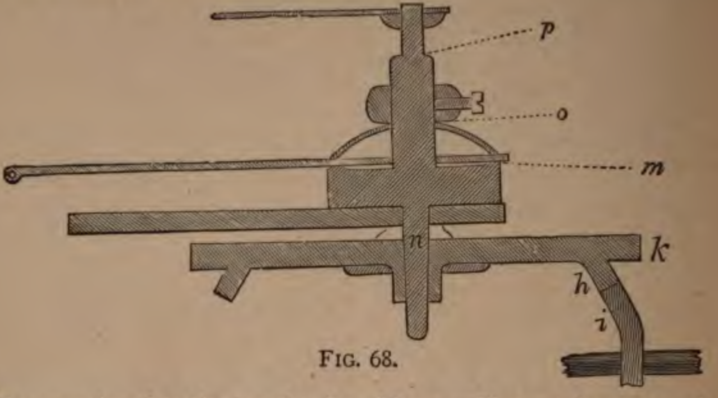


FIG. 68.

The operation of putting together is as follows:—First put the centre arbor and all upon it in the frame, and secure the same by the four pillar screws. Then place the finger-keys, the dial-plate, the springs for the keys, the dial, the index, and the glass together, and fix the whole on the wooden case. Lastly, place the magnet in its proper position, and, when all is ascertained to be correct, screw on the brass casing and the wooden bottom of the instrument.

The indicator and alarum may be taken to pieces, when necessary, and put together again, by marking the proper position of the several parts. In the indicator, pivots only require to be oiled, and that in very small quantities. The indicator, when good oil has been used, will work without attention for two or three years.

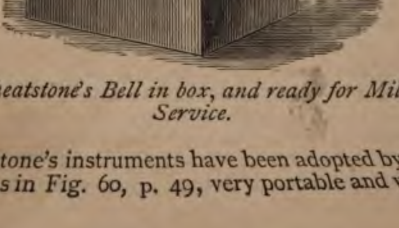


FIG. 69.—*Wheatstone's Bell in box, and ready for Military or other Service.*

Professor Wheatstone's instruments have been adopted by the army authori-*ties, and are made*, as in Fig. 60, p. 49, very portable and wholly independent

of all battery power, the trouble of putting batteries together, the supply of acids, breakage, and all the trouble that would be multiplied tenfold in the hurry of the battle-field. These instruments, as already described, work by a current developed by magnetism and by the use of steel magnets; they are made very strong and substantial, and are well calculated to bear the wear and tear of military operations conducted in the field.

The bell is rung, as nearly all other electric bells are rung, by clockwork wound up, but stopped by a "detainer." Directly the detent is removed by the current, the bell rings.

The same instruments, connected with enlarged dials, are used on board the iron-clads. We show an enlarged dial, and can easily understand how quickly the commander's orders could be conveyed to the engine-room.

FIG. 70.—*Wheatstone's enlarged Dials, such as are used in the Engine-rooms of Ships of War.*

The dials, of course, would have special orders printed on them, being those given constantly in the navigation of these immense vessels.

In a very short time, similar dials will be placed in the various rooms occupied by members in the House of Commons, and the dials will show what business is in progress and what has been done. The business to be transacted, being printed in a circular form, is laid upon the dial, and the hand points to that in progress, whilst all behind it is over.

The steering of the iron-clads is also to be conducted with the assistance of similar dials.

One of the most useful of Sir Charles Wheatstone's elegant and beautiful inventions is the instrument he has supplied to the editor of "The Times" newspaper to record the number of copies printed and printing. The editor

reads in his own room the progress of that great undertaking, the daily printing of "The Times."

FIG. 71.—*Wheatstone's Recording Instrument for Newspaper Offices or Public Buildings.*

This instrument will record from ten thousand to one million copies. The same contrivance the writer hopes to be able to adopt at the Polytechnic, so that, without moving from his office, he will be able to know the number of persons in the building.

These instruments culminate to their highest degree of perfection in the inventions of 1858 and 1867, viz., Wheatstone's Fast-speed Automatic Telegraph, of which the inventor gives the following particulars:

"My invention consists of a new combination of mechanism for the purpose of transmitting through a telegraphic circuit messages previously prepared, and causing them to be recorded or printed at a distant station. Long strips or ribbons of paper are perforated, by a machine constructed for the purpose, with apertures grouped to represent the letters of the alphabet and other signs. A strip thus prepared is placed in an instrument, associated with a rheomotor (or source of electric power), which on being set in motion moves it along, and causes it to act on two pins in such manner that, when one of them is elevated, the current is transmitted to the telegraphic circuit in one direction, and when the other is elevated, it is transmitted in the opposite direction; the elevations and depressions of the pins are governed by the apertures and intervening intervals. These currents, following each other indifferently in the two opposite directions, act upon a printing or writing instrument at a distant station, in such manner as to produce corresponding marks on a ribbon of paper moved by appropriate mechanism.

"I will proceed to describe more particularly the several parts of this telegraphic system, observing, however, that each part has its independent originality, and may be associated with other apparatus already known.

"*The first improvement* consists of an instrument for perforating the slips

of paper with the apertures in the order required to form the message. The slip of paper passes through a guiding groove, at the bottom of which an opening is made sufficiently large to admit of the to-and-fro motion of the upper end of a frame containing three punches, the extremities of which are in the same transverse line. Each of these punches is capable of being separately elevated by an appropriate finger-key. By the pressure of either finger-key, besides the elevation of its corresponding punch in order to perforate the paper, two different movements are successively effected—first, the raising of a clip, which holds the paper firmly in its place, and, secondly, the advancing motion of the frame containing the three punches, by which the punch which is raised carries the ribbon of paper forward the proper distance during the reaction of the key consequent on the removal of the pressure; the clip first fastens the paper, and then the frame falls back to its normal position. The two external keys and punches are employed to make the holes which, grouped together, represent letters and other characters, and the middle punch to make holes which mark the intervals between the letters. The perforations in the slip of paper appear thus:

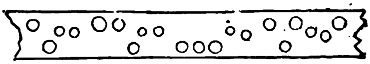


FIG. 72.

"The second improvement consists of an apparatus which may be called the transmitter, the object of which is to receive the slips of paper prepared by the previously described instrument or perforator, and to transmit the currents produced by a voltaic battery or other rheomotor in the order and direction corresponding to holes perforated in the slip; this it effects by mechanism somewhat similar to that by which the perforator performs its functions. An eccentric produces and regulates the occurrence of three distinct movements: 1st, the to-and-fro motion of a small frame, which contains a groove fitted to receive a slip of paper, and to carry it forward by its advancing motion; 2nd, the elevation and depression of a spring clip, which holds the slip of paper firmly during the receding motion, but allows it to move freely during the advancing motion; 3rd, the simultaneous elevation of three wires placed parallel to each other, resting at one of their ends on the axis of the excentric, and their free ends entering corresponding holes in the grooved frame; these three wires are not fixed to the axis of the excentric, but each of them rests against it by the upward action of a spring, so that when a light pressure is exerted on the free ends of either of them, it is capable of being separately depressed. When the slip of paper is not inserted, and the excentric is in action, a pin attached to each of the external wires passes, during each advancing and receding motion of the frame, from contact with one spring into contact with another spring, and an arrangement is adopted, by means of insulations and contacts properly applied, by which, while one of the wires is depressed and the other remains elevated, the current passes from the voltaic battery to the telegraphic circuit in one direction, and passes in the other direction when the wire before elevated is depressed, and *vice versâ*; but while both wires are simultaneously elevated or depressed, the passage of the current *is interrupted*. When the prepared slip of paper is inserted in the groove, *and moved onwards*, whenever the end of one of the wires enters an aperture

in its corresponding row, the current passes in one direction, and when the end of the other wire enters an aperture of the other row, it passes in the other direction; by this means the currents are made to succeed each other automatically in the proper order and direction to give the requisite variety of signals. The middle wire only acts as a guide to the paper during the cessation of the currents.

"The wheel which drives the excentric may be turned by hand or by the application of any motive power. Instead of a voltaic battery, a magneto-electric or an electro-magnetic machine may be employed as the source of electric power. In this case the transmitter and the magneto-electric or electro-magnetic machine form a single apparatus moved by the same power, and they are so adapted to each other, that the shocks or currents are produced at the moments the pins of the transmitter enter the apertures of the perforated paper.

"The transmitters just mentioned require only a single wire of communication, and currents in both directions are available for printing the signals; but in some cases it may be advantageous to employ two telegraphic wires, and to use the inversions of current to bring back the pens or markers without the aid of reacting springs. In this case the only modification of the apparatus required is in the disposition of the insulations and contacts necessary to transmit in their proper order the currents from the rheomotor into the two wires.

"The third improvement is in the recording or printing apparatus, which prints or impresses legible marks on a strip of paper, corresponding in their arrangement with the apertures in the perforated paper. The pens or styles are depressed and elevated by their connection with the moving parts of the electro-magnets; they are entirely independent of each other in their action, and are so arranged that, when the current passes through the coils of the electro-magnets in one direction, one of the pens is depressed, and when it passes in the contrary direction the other pen is depressed; when the currents cease, light springs restore the pens to their usual elevated positions. The mode of supplying the pens with ink is as follows:—A reservoir, about an eighth of an inch deep, and of any convenient length and breadth, is made in a piece of metal, the interior of which may be gilt, in order to avoid the corrosive action of the ink placed in it. At the bottom of this reservoir are two holes, sufficiently small to prevent by capillary attraction the ink from flowing through them. The ends of the pens are placed immediately above these small apertures, which they enter when the electro-magnets act upon them, carrying with them a sufficient charge of ink to make a legible mark on the strip of paper passing beneath them. The motion of the paper ribbon is produced and regulated by apparatus similar to those employed in other register or printing telegraphs.

"Instead of reacting springs for restoring the position of the pens, the attractive or repelling force of small permanent magnets may be employed. All the essential parts of my new recording or printing telegraph are included in the previously mentioned three improvements. The following improvements are either auxiliary or substitutions for parts already mentioned.

"The fourth improvement is an instrument which I call a translator; its object is to translate the telegraphic signs, consisting of successions of points or marks, adopted in this system, into the ordinary alphabetic characters. In the system I have adopted, limiting the number of points in succession to four, thirty distinct characters are represented.

"The instrument presents externally nine finger-stops, eight of which are arranged in two parallel rows, four in each, and the remaining one is placed separately.

"The principal part of the mechanism within is a wheel, on the circumference of which thirty types are placed at equal distances, representing the letters of the alphabet and other characters; other mechanism is so disposed and connected thereto, that when the keys of the upper row are respectively depressed, the wheel is caused to advance 1, 2, 4, or 8 steps or letters, and when those of the lower row are in like manner depressed, the wheel advances respectively 2, 4, 8, or 16 steps. By this disposition, when the stops are touched successively in the order in which the points are printed on the paper—touching the first stop for one point, the first and second for two points, &c., and selecting the stops of the upper or lower row, according as the point is in the upper or lower row of the printed ribbon—the type wheel will be brought into the proper position for placing the letter corresponding to the succession of points over a ribbon of paper. The ninth stop, when it is pressed down, acts to impress the type on the paper, to cause the advance of the paper, in order to bring a fresh place beneath the type-wheel, and subsequently to restore the type-wheel to its initial position.

"The fifth improvement is a modification of the electro-magnets of the instrument of the third improvement, which enables the pens to go back to their normal positions when the currents in the telegraphic circuit cease, without the aid of reacting springs or permanent magnets. An extra coil of wire is wound round each of the electro-magnetic bars, which act on one side of each of the double magnetic needles appropriated to the two pens. These coils are entirely insulated from those connected with the telegraphic circuit, and form together a short local circuit, in which a feeble voltaic current continually circulates, in consequence of the interposition of a small rheomotor; by this current the needles are held, when no current exists in the telegraphic circuit, constantly attracted towards these electro-magnets. When, however, the current transmitted through the telegraphic circuit acts on the coils, besides its direct action to cause the deflection of one of the double needles and the detention of the other, it neutralizes the current of the local battery in that electro-magnet where its effect for the time would be disadvantageous.

"The sixth improvement consists in the application of ribbons of paper prepared by the perforator, and passed through the transmitter as heretofore described, to produce the successive motions of a magnetic needle or needles corresponding to the signals required, whether separately employed for this purpose or in conjunction with the printing apparatus already mentioned."

Even these beautiful instruments were not considered perfect by the indefatigable inventor, and we again find him, after a most severe illness, recording, in 1867, further great improvements in the mechanism of all their parts.

IMPROVEMENTS IN ELECTRIC TELEGRAPHS, AND IN APPARATUS CONNECTED THEREWITH.

"My present invention (1867) consists in certain improvements in the various instruments constituting the electric telegraph system described in the specification of the patent granted to me on the second day of June, A.D. 1858, No. 1239.

"*This system comprises* three distinct apparatuses: first, a perforating

machine for preparing the messages to be sent on the strips of paper or other suitable material;

"Second, a transmitter, or apparatus for receiving the strips of paper so prepared, and for transmitting the currents produced by a voltaic battery, magneto-electric machine, or other rheomotor, in the order corresponding to the holes perforated in the strip, the direction and sequence of these currents being governed by pins, or other suitable apparatus, disposed so as to enter the perforations, and operating in a manner analogous to that in the mechanism of a Jacquard loom, and the strip being advanced intermittingly by the action of pins or other apparatus appropriated for that purpose;

"And, third, of a recording or printing apparatus adapted to print or impress marks on a strip of paper, such marks corresponding in their arrangement with the currents transmitted to the telegraphic line and with the apertures in the perforated paper.

"Having separately described each system of recording telegraphs, with the improvements which form the objects of the present specification, I proceed to designate those points which I specially claim as new.

"First, the modification of the perforator for the dot-printing telegraph, which enables it to prepare the strips of paper with an uninterrupted series of central apertures; this modification, described as the first improvement, consists of the mechanism being so arranged that when either of the keys corresponding with the outer apertures is depressed, besides acting on its own punch, it carries with it the punch which corresponds with the central apertures, while the latter is alone acted upon by means of another key causing the perforation only of a single aperture at a time.

"Second, the modification of the perforator, described as the fourth improvement, having five punches, and the mechanism so arranged that, when the first key is pressed, three of the punches in the order described are simultaneously acted upon; when a second key is depressed, four of the punches are in like manner simultaneously acted upon; and when a third key is depressed, the single punch only of the central line is acted upon. I claim also, in connection with this arrangement, the mechanism by which when either the first or third keys are pressed down the paper advances only a single space, and when the second key is depressed it advances two spaces; but be it understood that I do not claim the advance of the paper by unequal spaces, unless in connection with the arrangement of the punches described.

"Third, the additions of extra keys to the preceding modification of the perforator, with additional punches, described in the fifth improvement, which are so arranged that each additional key when depressed, while it punches simultaneously all the required apertures, shall advance the paper at once three, four, or more steps, so that all the perforations may be simultaneously made which are necessary to cause lines of the various required lengths to be marked or printed by the receiving instrument.

"Fourth, the modification of the transmitter, described as the second improvement, whether actuated by a magneto-electric machine or by a voltaic battery, in which the central needle alone has a to-and-fro motion for the purpose of propelling forward the strip of paper by means of the central apertures alone, and not also by means of the external apertures and outer pins, as described in the second improvement of the specification of my patent, *No. 1239 (A.D. 1858)*.

"*Fifth, the modification* of the transmitter, described as the sixth improve-

ment, which is adapted to send into the telegraphic circuit short currents at various intervals and alternately in opposite directions, so as to determine the occurrence of printed lines and intervals of various lengths in the receiving instrument: in this modification one current-governing needle has a to-and-fro motion simultaneously with the central needle, while the other has no such motion, the latter acting only while the paper is at rest, and the former while it is in motion.

"Sixth, the modification of the transmitter, described as the eighth improvement, which is suited to send into the telegraphic circuit currents of various lengths in one direction only in a different way to that described as the seventh improvement in my patent, No. 2462 (A.D. 1860). The characteristics of this new method are, first, that lines of any lengths can be produced, instead of lines of two different lengths only; second, that the short lines occupy a shorter space on the paper than the long lines do; and, third, that strips of paper prepared by the perforators of the third and fourth improvements may be employed to regulate the motions of the needles in order to produce the required effects.

"Seventh, the modification of the dot-printing receiving instrument, described as the third improvement, in which the pens or markers are acted upon by one set of electro-magnets and magnetic bars, instead of by two sets, as described in the specification of my patent, No. 1239 (A.D. 1858).

"Eighth, that modification of the printing apparatus of the receiving instruments of the second and third systems described as the eighth improvement, by means of which lines of various lengths are printed with great rapidity, certainty, and distinctness. The characteristic distinction of this mode of printing is, that the inking-disc and tracing-disc are both independently kept in motion by the maintaining power, and are not in actual contact with each other, and that the ink is retained on the circumference of the inking-disc by capillary attraction."

We now give the description of the three instruments:

I. The perforator.
II. The transmitter.
III. The recorder.

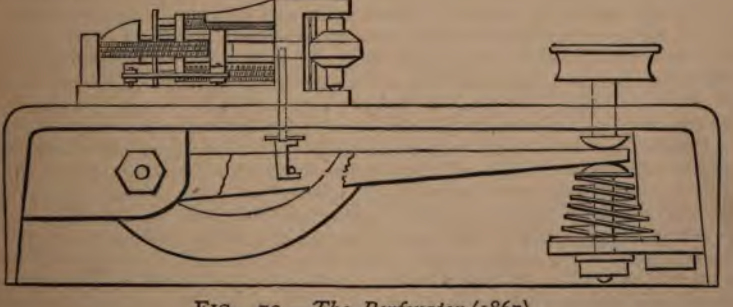


FIG. 73.—*The Perforator* (1867).

"*The present improvement* provides for the continuity of the middle perforations *of the paper strip*. The punching-plate carries three punches (Fig. 74)

placed transversely to the path of the paper through the machine. Three lever finger-keys act upon the punches in such a manner that whenever either of the outer keys is depressed, it acts upon the punch which belongs to it, and at the

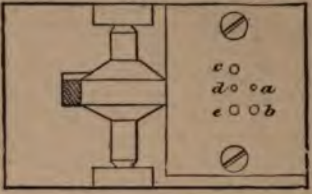


FIG. 74.

same time carries with it the middle punch by means of a collar which is fixed thereto, and simultaneously perforates the two apertures; but the depression of the middle key acts upon the middle punch alone, and perforates a middle aperture only, which is equivalent to a space in the receiving instrument. On the removal of pressure from any finger-key, the corresponding punch or punches is or are restored to its or their normal positions by means of a re-acting spring or springs. A lever and link arrangement, moved by either of the three keys, draws back the paper-moving lever during the depression of a key; the release of a key permits a reacting spring to force the paper-moving lever forwards and to advance the paper one step, the said lever having a rough end next to the paper strip for that purpose: this mechanism propels the paper quite independently of the middle row of holes.

"Fig. 75 is a perspective view of a transmitter arranged to work with two line wires; in this instrument, besides the necessary change in the insulations and contacts, the mechanical arrangements are slightly varied, the construction shown being more convenient when two line wires are employed than that first described. *a* is a permanent magnet, and *b* is an armature mounted on an axis *c*, so as in revolving to pass in front of the poles of the magnet. On the axis *c* there is a toothed wheel, *d*, which drives the pinion *e* on the vertical axis *f*, so that this axis makes twice as many revolutions as the axis *c*; at the upper end of the axis *f* is a cam, *g*, arranged to act on the pin *h*, which is mounted on a rocking-frame similar to the rocking-frame of the transmitter already described. The pin *h* is kept in contact with its cam *g* by a spring *i*. The form of the cam is such that the forward motion of the frame is gradual, but its return motion takes place as rapidly as the spring *i* will react. *j* is another cam on the axis *f*; it comes in contact with a projection on the lever *k* just as the return motion of the rocking-frame is going to take place, and so causes this lever to draw down the three needles carried by this frame. At the same time the tail of the lever *k* presses on the end of another lever *l*, which is fixed to the spring-clip *m*, and so causes the clip, by turning slightly on its axis, to nip the paper under it. It will be seen that the two outside needles carried by the rocking-frame have projections from their lower ends, and when they are allowed to rise by the perforated paper, as before explained, their ends come in contact with the springs *n* and *o*, which are insulated from the rest of the instrument, and are in communication with the two line wires. On the

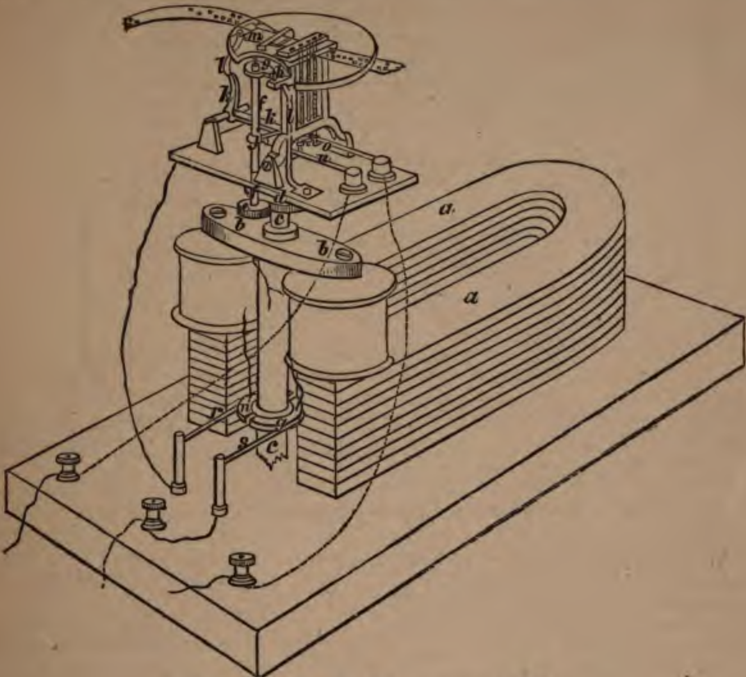


FIG. 75.—*The Transmitter* (1858).

axis c a metal disc is mounted; it is made in two parts, p and q, which are insulated from each other and from the axis. r and s are two springs, which press on the periphery of the disc as it revolves; the spring r is in metallic communication with the working parts of the instrument, and the spring s is insulated from these parts, but is put into metallic connection with the earth. When one of the needles of the rocking-frame comes into contact with its corresponding spring, n or o, it brings the line wire in connection with the spring into metallic communication with the working parts of the instrument, and any currents or shocks transmitted to these flow into the line wire. From the construction of the apparatus, the contact between the needles of the rocking-frame and their corresponding springs when established lasts during half a revolution of the axis c, and in this period two currents in opposite directions are transmitted into the line wire. The first current acts to bring one of the pens or markers of the receiving instrument into contact with the surface to be marked, and the second current to bring this pen or marker to its original position. It is evident that, if necessary, the instrument above described may be worked with one line wire only, without any change being made in the instrument; all that is necessary is that, in perforating the str

for the message, only one of the outside finger-keys of the perforator should be employed (the alphabet or signs employed being modified accordingly). Or the perforating instrument and the transmitting instrument may both be modified, if desired, so as to be suitable only for working with one line wire, by constructing the perforator with two in place of three finger-keys and punches, and the transmitter with two in place of three needles."

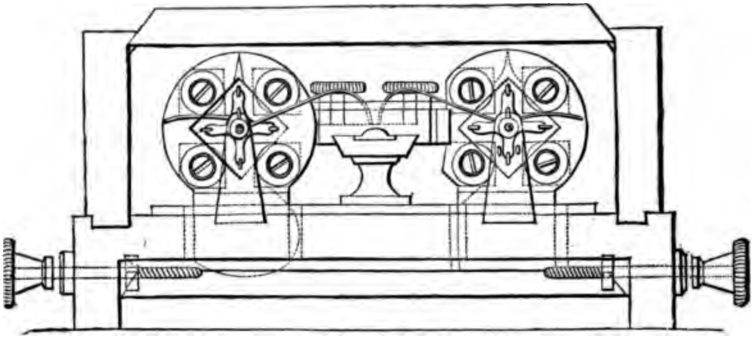


FIG. 76.—*The Recording or Printing Instrument* (1858).

Another improvement is in the recording or printing apparatus; but as the chief parts of this instrument have already been described with sufficient minuteness, it is only necessary to refer our readers to page 406 for the details of the beautiful mechanism which regulates the marking of the slips of paper and the supply of ink to the dotting apparatus.

The improved instruments are now working between London and Newcastle, Edinburgh, Manchester, and Glasgow; and they can send and print *messages from seventy to one hundred and twenty words per minute*, according to their exigences. They are also used in connection with the submarine cable extending from Newcastle to Denmark.

SIR CHARLES WHEATSTONE'S LAST AND MOST COMPLETE TELEGRAPHIC APPARATUS,

AND OTHER BEAUTIFUL APPLICATIONS OF ELECTRICITY--THE CHRONOSCOPE AND TELEGRAPH THERMOMETER FOR GREAT ALTITUDES.

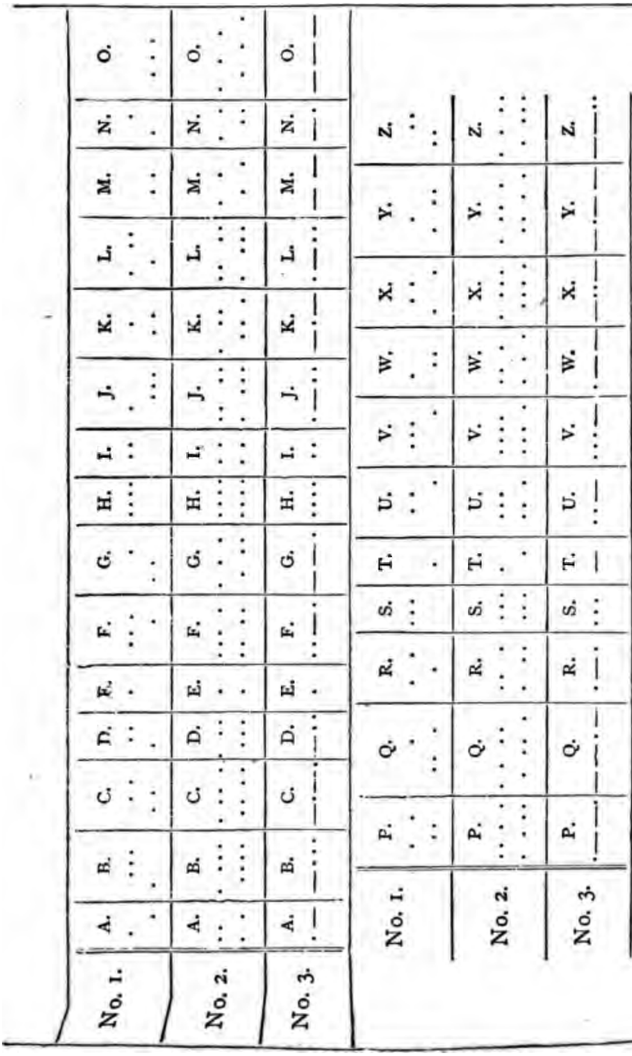


FIG. A.—*The various Telegraphic Alphabets.*

No. 1.—The Dot Printed Alphabet, and also the perforated slip for the same system, with the transmitting perforations omitted.
No. 2.—The Line or Morse Printing Perforated Slip, with the transmitting perforations omitted.
No. 3.—Line or Morse Printed Alphabet.

When Sir Charles Wheatstone turned his attention to fast-speed telegraphs, the result was the dot printing. He attained 700 letters per minute; but the telegraph companies objected to it, because it necessitated the clerks learning the new alphabet, the dots being in two lines (No. 1, Fig. A), the lower dot taking the place of the dash in the line or Morse alphabet. In addition to the above objections, it is not suited for submarine cables requiring reversals for rapid working; therefore, Sir Charles brought out a transmitter to work the inking Morse. But words could be transmitted quicker than the instrument would print; therefore, it remained for Sir Charles to bring out a rapid printer,

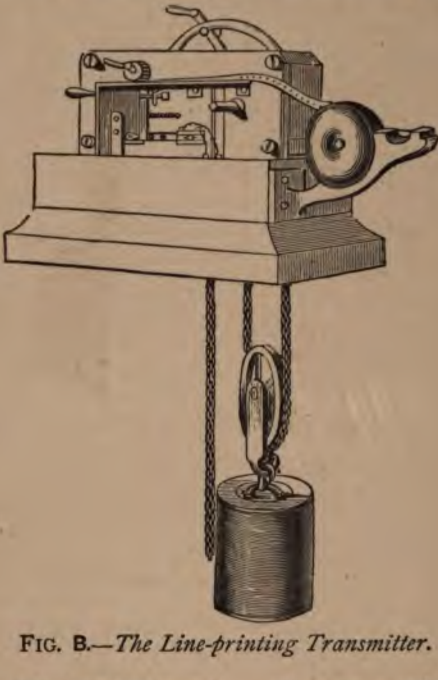


FIG. B.—*The Line-printing Transmitter.*

which he accomplished, and it is now known by the name of the "line-printer," printing the dot and dash alphabet (No. 3, Fig. A), such as is used by all telegraph companies, printing 600 letters per minute; the dot and line printing differing especially in this respect—the line currents always being inverted alternately; in the dot, three or four currents in the same direction sometimes follow each other.

THE LINE TRANSMITTER WITH MAINTAINING POWER (Fig. B), is a modification of the transmitter described as the sixth improvement for receiving the strip prepared by either of the perforators described as the fifth improvement, and transmitting voltaic currents along the telegraphic conductor to the receiving instrument at the distant station, in accordance with the arrangement of the

perforations in the paper strip (motion being produced by a weight); the propulsion of the paper strip and the makings of the contacts with the batteries are accomplished by the same power; and, by means of levers, beam, eccentric, and springs, the upper ends of two vertically moving pins, being alternately pressed against the paper, are free to enter the perforations, if any present themselves; or, being prevented from entering the paper by the absence of apertures, they regulate the succession, frequency, and direction of the electric currents sent into the telegraphic circuit.

The action of the pins in conjunction with the paper strip is as follows: the

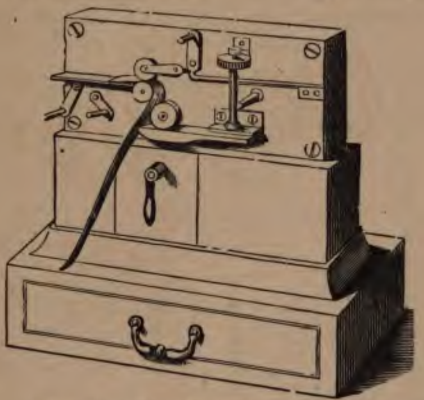


FIG. C.—*Line Printer or Receiver.*

only means of propulsion of the paper is by the pins of a star-wheel entering the middle perforations, and by its rotation moving the paper forward, the strip being held down by a broad-toothed wheel pressing it against the paper-ledge, the vertically moving pins entering the notches in the before-mentioned wheel, pass through an aperture in the paper, and are carried forward by it, thus not interfering with the duration of contact at the lower end of the pins; the reacting springs restore them to their normal position on their downward movement, effected by the levers to which they are attached receiving an up-and-down motion from an oscillating beam, connected with an eccentric driven by the maintaining power; and, on the arrival of an outer aperture on one side of the middle line of holes, the pin of that side will enter and transmit a current in one direction; and on the presentation of an aperture on the opposite side, the pin will also enter and transmit a current in an opposite direction, the apertures in the paper regulating the frequency, direction, and duration of the current sent into the telegraph line.

In the Line Printer or Receiver (Fig. C), the magnetic armatures are placed in a vertical position; the central axis is prolonged so as to carry the cross-piece, through an aperture in the extremity of which a horizontal rod passes; on this is mounted at one extremity the small, light tracing-disc, whilst the opposite end, which is loosely centred, so as to be capable of a slight lateral movement, carries a small toothed wheel; this wheel, gearing with the main-

taining power of the instrument, imparts a rotatory motion to the tracer, at the same time that the axis is capable of receiving a to-and-fro motion in a horizontal plane from the movement of the armatures and arm.

In the same vertical plane, and immediately beneath the tracing-disc, is an inking-disc, caused to rotate, by appropriate gearing, with the maintaining power of the apparatus: this disc revolves in a reservoir containing ink or other suitable marking fluid. The periphery of the disc is slightly hollowed, and the edge of the tracing-disc just enters this hollow without contact or friction with the inking-disc; during the revolution of the disc, capillary attraction keeps the hollow full of ink, and a constant and uniform quantity will be supplied to the tracing-disc.

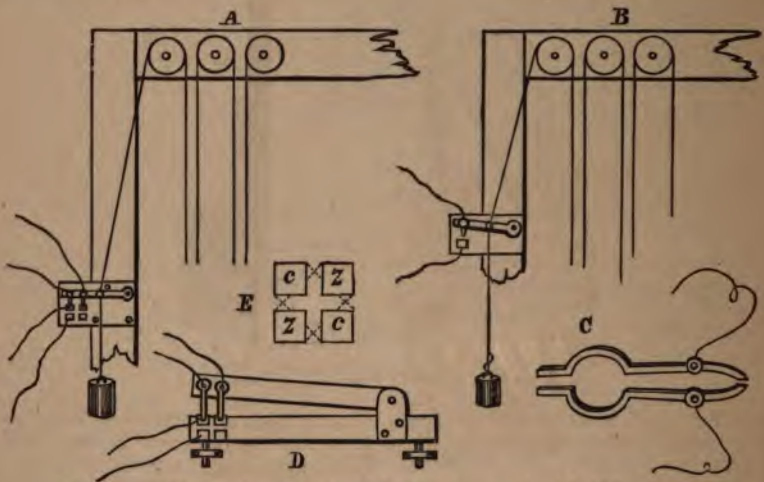


FIG. D.—*The various parts of Apparatus used with Wheatstone's Chronoscope.*

The paper intended to receive the marks is drawn forward at suitable speed over a roller in close proximity to one edge of the tracing-disc. It will be understood that a series of instantaneous alternate currents passing through the electro-magnet causes a to-and-fro motion of the tracing-disc, a current in one direction pressing the tracing-disc against the paper, where it will remain, by reason of the residual magnetism of the electro-magnets retaining the armatures in that position, until a current in the opposite direction withdraws the tracer from the paper. By this arrangement lines of more than two lengths can be printed with perfect accuracy in connection with the perforator with five keys described as the fifth improvement. Another remarkable instrument is

WHEATSTONE'S CHRONOSCOPE.—The various parts of this arrangement are shown at Fig. D, and employed to ascertain the velocity of projectiles. They will be readily understood when we describe the ball-holder and target used in the falling bodies experiments. A and B are enlarged parts of screens;

C is the ball-holder closed to receive the ball, each side being insulated. The electric circuit is not complete; but, at the moment of the release of the ball, the two sides will meet and complete the circuit, which, traversing in one direction, will start the chronoscope: this will continue running until the ball strikes the target, when it will reverse the current and stop it. The method of reversing is readily understood by E and D, Fig. D. Two springs are fixed to the target, which is hinged at one end, the other end falling when the ball strikes it. The springs slide over the reversing-piece, consisting of two poles of the battery, which are bridged over at the back, as indicated by the dotted lines, E.

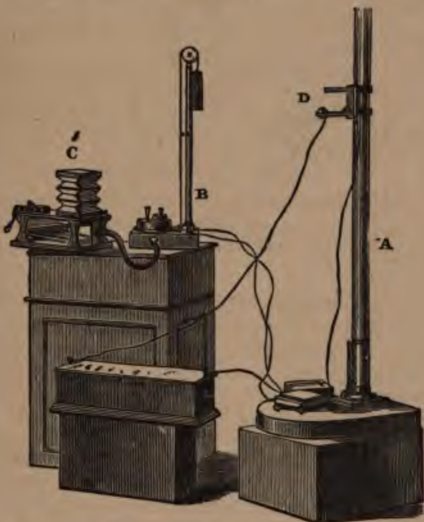


FIG. E.—*The Chronoscope in Elevation.*

Fig. E represents the chronoscope as arranged for indicating automatically the time occupied by falling bodies. A is a column, upon which the ball-holder slides, the target being placed at the base; B is the chronoscope, consisting of clockwork mechanism, with two dials, one divided into hundredths, and the other into thousandths, of a second, with hands like a watch, motion being communicated to it by a weight passing over a pulley, which is regulated by an escapement with a musical spring, tuned to a thousandth part of a second, caused to sound by the pressure of air from the bellows, C. The clockwork is in two distinct parts, the driving and the dial parts; they are made to gear by sensitive magnetic needles and an electro-magnet. One pole of the battery is connected with the ball-holder, the other with the target; two wires from the target connect it with the chronoscope, one wire connecting the ball-holder with the target. The poles of the battery are so arranged that on the release of the ball *the electric circuit is completed*, and the dials are brought into gear with the *driving part; the current* is reversed the instant the ball strikes the target, and

FIG. F.—*Wheatstone's Projectile Arrangement.*

The targets, B and C, connected with the battery, D, and Wheatstone's chronoscope, arranged to receive and indicate the velocity of the shot from the Armstrong gun, A.

the dials are disengaged, enabling the operator to read off the time by the hands, without the tedious calculation necessary by other means generally employed. The almost inexhaustible inventive faculty of Wheatstone, ever devising new or improving older inventions, is again displayed in his New Telegraph Thermometer (Fig. G).

This instrument was invented by Wheatstone to supply a scienific want, viz., the means of ascertaining, day or night, without making tedious ascents, the temperature of any lofty summit—such as that of Mont Blanc.

The cut (Fig. G) represents the general internal arrangement of the instruments requisite to ascertain the temperature at a distant point, two insulated wires connect them, the earth being used to form the third conductor.

The apparatus includes the thermometric arrangement, and also an electro-magnetic contrivance for converting the vibrations of magnetic needles between electro-magnets into a circular motion, for the purpose of altering the electric conduction from one circuit to another.

In order to indicate the temperature measured by the instrument above mentioned, there is an electro-magnetic arrangement, and also a permanent compound magnet with fixed coils, having an armature opposite to its poles, capable of being rotated by a handle, to produce a series of alternately inverted currents.

Fig. G, p. 71, represents the internal construction of both instruments; the dotted and other lines represent the wires necessary to conduct the electric currents. In the knob A, which is attached to the glass covering the dial, is contained a metallic thermometer, having a hand or pointer attached to its axis; and in the same line is an insulated axle, with arms, C and D, proceeding from it, a spiral spring tending to maintain the contact of the arm C with the hand B; under this axle is a toothed wheel, F, with a spring-catch, E, the said wheel gearing with the pinion G, connected by a spindle with the wheel H, mounted

on an oscillating arm proceeding from the axle, carrying the magnetic needles placed between two coils (only one is shown in the drawing) analogous to the indicator of the alphabetical telegraph (Fig. A). O K is a similar arrangement; M N is a magnetic machine.

When an observation is about to be made, the dial of the indicator is adjusted to zero by means of the rim P, and the handle N rotated, producing a series of positive and negative currents, which may be imagined to take the course indicated by the arrows, coming from a coil, passing through wire 6 to

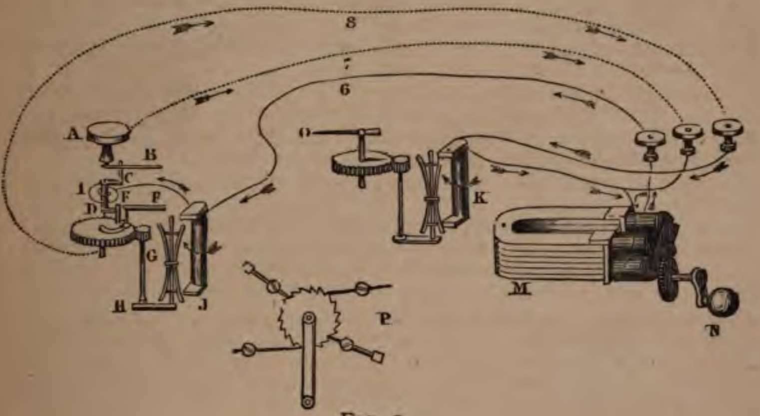


FIG. G.

the coils J, the short wire to the axle C D, to the hand B, and wire 7 to the coils of the magnets, thus completing the circuit, causing the needles between the coils J to oscillate by their alternate attraction and repulsion, communicating that motion by the arm H J to the wheel H, which, by its peculiar construction, will rotate, communicating that motion, by means of the pinion G, to the wheel F in the direction G E D; the pin E, pressing against the arm D, will draw away the arm C from the hand B; the piece D C will make a partial rotation on its axis, or describe an arc by the arms C D, the angle being the number of the degrees of temperature, thus breaking the circuit at C B, and completing it through D E; the wheel F, and wire 8, including the coils K, imparting motion to the hand or pointer O by the same means to those already described, which will continue until the catch F arrives at the pin L, corresponding to the zero in the scale of the instrument, when it will disengage the pin E from arm D, the spiral spring forcing arm C in contact with the hand B, thus restoring the circuits to their former condition.

When the circuit is complete through the wires 6 and 7, only the coils J come into action; but when the connections are made through wires 6 and 8, both coils are caused to act, moving the arm C in the thermometer from the highest point indicated on the dial to the zero, and in the indicator from the *adjusted zero to the highest* point, when the motion of the pointer will cease, *indicating the state of the* dial B A.

In a paper read by Sir Charles Wheatstone before the Academy of Sciences at Paris he thus sums up the advantages of his automatic printing telegraphic system:

"I will conclude by offering a few remarks on the advantages possessed by this system.

"Whatever practical dexterity may be acquired by a voluntary operator, the result arrived at will be far inferior to that obtained by the automatic process, which is only limited by the rapidity with which the recurring motions of the transmitter can be effected. By the present construction of the instrument, five times the quantity of signs at present used can be transmitted to moderate distances; though for very considerable distances this rapidity may be limited in conductors subjected to inductive influences by the tendency which rapidly recurring short currents have to coalesce.

"But even if there were no advantage in point of rapidity possessed by the automatic over the voluntary process of transmission, its other advantages would be incontestable. For the profitable working of a telegraphic line, it is necessary that the operator should manipulate as rapidly as is consistent with a correct transmission of the message: it requires great skill to become a proficient in such manipulations, even when the language in which the despatch is sent is quite familiar to the operator; but if he would send a despatch in a language unknown to him, or in cipher, he is obliged to proceed with caution and slowness. In my new system the prepared messages are transmitted with equal rapidity in whatever language or cipher they may be; and as the perforated bands may be prepared at leisure, and be subjected even to the revision of a corrector, guarantees of accuracy are obtained which cannot be afforded by the system of immediate voluntary transmission. Several clerks will be required to prepare messages for a single telegraphic line in constant activity; but, in an economical point of view, their time is of far less importance than the time occupied by the transmission of a message.

"Another advantage this new system possesses is that the same prepared message may be transmitted through any number of distinct lines, if not simultaneously, at least in such rapid succession as to be equivalent thereto; and besides, without any fresh labour, the same message may be retransmitted, if thought necessary; and service messages in constant use may be preserved for transmission whenever they may be required.

"Were this automatic system generally adopted, it might in many instances be more convenient to prepare the messages at the offices from which they are sent, the instrument for effecting this purpose being very portable and of small cost. The operations at the telegraph office would in these cases be limited to passing the perforated band through the transmitter at one station and receiving the printed message at the other, the translation as well as the preparation of the message devolving on the department of the administration to which it relates.

"In the present case it is not the question to substitute one kind of acquired skill for another kind equally difficult to attain, which would entail great labour on all the employés. The great practical dexterity at present required being dispensed with, and the principal and most laborious operation being entirely automatic, there is little to learn, though there may be something to forget."

THE ATLANTIC TELEGRAPH CABLE.

The resistance of a conductor of any given metal is *directly proportional to its length*, and *inversely proportional to its thickness* or cross section.

It was soon found to be necessary, in experiments with thousands of miles of cable or insulated wires, to adopt some standard or starting-point, in order to ascertain exactly the resistance of the whole.

The matter was put into the hands of a committee of the British Association, who determined that an English mile of pure copper wire, No. 16, should be the B. A. unit; they further constructed a wire of silver and platinum, because it was little affected by temperature, which they deposited as the standard of comparison, and this length of wire they estimated in figures to be 13·59 of the length of the copper wire. Bobbins upon which hundreds and thousands of miles of copper wire No. 16 would have to be wound would be too bulky and cumbersome to manage; it has, therefore, been arranged that German silver, an alloy of about 60 parts of copper with a fraction of lead, 25 zinc, and 15 nickel, should be employed, because it has about thirteen times less conducting power than the same-sized copper wire; consequently the standard unit would be represented as follows:

B. A. unit of German silver wire = 13·59 of an English mile.

The bobbins, having 13·59 of an English mile of German silver wire wound upon them, represent, therefore, a resistance equal to one mile.

The length of the great Atlantic cable, stretching between Valentia in Ireland and Newfoundland in America, a distance of 3,500 miles, is 1,858 knots, and each knot, equal to $7\frac{1}{2}$ nautical miles, has an electrical resistance, at a temperature of 75° Fahrenheit, equal to 4·272 of the above-named B. A. units. Consequently 1,858 knots, multiplied by 4·272, would give the resistance of the whole cable as 7,937 B. A. units; or, allowing for diminished resistance caused by the low temperature of the bed of the Atlantic, and deducting a certain number of units for that, we have, say, 7,500 B. A. units.

The resistance of the cable of 1865, according to Mr. Latimer Clark, is 7,604 B. A. units. The resistance of the last new cable, 1866, is 7,209 B. A. units. It is so much better, and the instruments are so vastly improved, that they can send from eighteen to twenty words per minute, instead of, as formerly, only two and a half. The new cable has three times more speaking power now it is immersed in the Atlantic than it had on board the Great Eastern.

At the commencement of the article on Electricity, great stress was laid upon the explanation of the phenomena of induction. The conducting wires of the Atlantic cable, formed of a strand of seven wires, each 0·048 inch in diameter, and together equal to a wire of 0·144 inch diameter, are surrounded with, and insulated by, gutta-percha.

Such being the case, it is easy to understand that, when conveying an electrical current, it must become charged like a Leyden jar. The wire is the inner metallic coating, the gutta-percha is equivalent to the glass, and the salt water outside the other metallic coating. This enormous Leyden jar measures in its inner coating about 425,000 square feet, and it was the charge maintained by *the cable that seemed* at first to negative and destroy all hope of sending *messages quickly*. This very property is now found to be most valuable, and

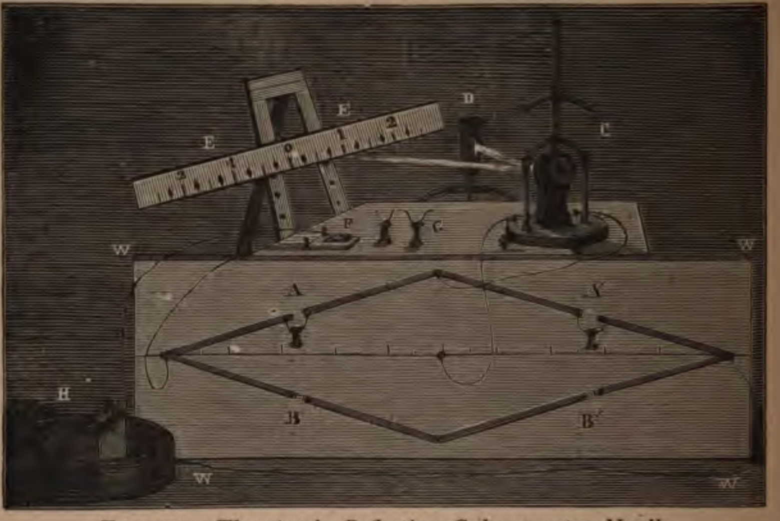


FIG. 77.—*Thompson's Reflecting Galvanometer Needle.*

C, The galvanometer; D, the oxy-hydrogen light; E E, the scale; W W W W, the Wheatstone bridge F, the key; G, extra-resistance coils; and H, the battery.

is made use of to expedite the sending of the signals, and in brief terms may be thus described:

The cable is first charged until, like a Leyden jar, it will bear no more. In order to send a message, it is discharged; and it is the latter operation, acting upon instruments of wondrous delicacy, that enables the operator to send the message.

Sir William Thompson's reflecting galvanometer needle is a notable illustration of the perfection to which a galvanometer may be brought; and his original instrument has been surpassed and brought up to a still higher pitch of refinement by Mr. Becker, the learned and obliging head of the instrument department at Messrs. Elliott's. The writer understood him to say that he was making one to show *a resistance of one in a million units.*

Mr. Becker arranged a most excellent series of instruments for demonstrating at the Polytechnic. The Thompson's reflecting galvanometer needle with Wheatstone's bridge are shown above (Fig. 77), as exhibited at the above-named institution by the writer.

The reflecting galvanometer needle must first engage our attention. It consists of two large flat bobbins, B B (Fig. 78), upon which are wound many hundred yards of insulated fine copper wire, and, in the instrument made for the writer, they were placed on hinges, so that they could be placed down, like the lid of a box, to disclose the delicate needle—a small magnet, A, made of watch-*spring about an inch long,* and weighing only a few grains, and hung by a very *narrow piece of tape;* because a filament of silk, if made the suspender, would *have caused the instrument* to be too delicate for lecture-room purposes.

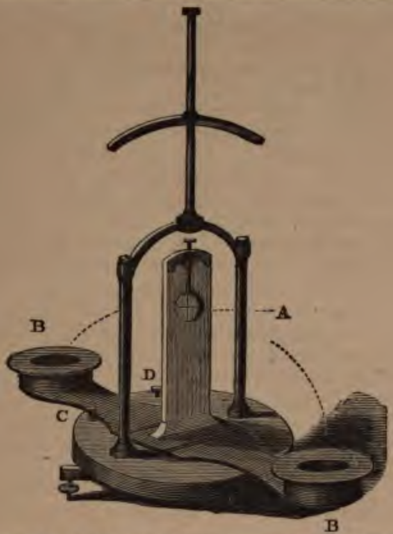


FIG. 78.—*Thompson's Reflecting Galvanometer Needle, with the Bobbins opened to show the suspended Needle.*

Fastened to the little magnet is a circular mirror, ground slightly concave, and weighing only a few grains; upon this is thrown from an aperture in a copper lantern a few rays from the oxy-hydrogen light. These are reflected upon a scale of 5 ft. 6 in. in length, so that the spot of light when it traversed the scale could be seen by an audience of one thousand people.

The movements of the spot of light are, of course, those of the magnet, and in order that the latter should be acted upon only by the currents sent through the instrument, and not by terrestrial magnetism, a curved steel magnet, working up or down or right and left, or a brass rod, is placed above it, and is most convenient for keeping the axis of the little mirror A, with its attached magnet, exactly between and parallel with the two bobbins B B, or, in other words, reflecting the spot of light to zero. C and D represent the connecting screws.

But, perfect as this galvanometer is, it would not have enabled the writer to teach others much about resistances and other interesting points connected with the Atlantic Telegraph cable, unless he had used an instrument for which sufficient credit has not been given to its distinguished inventor, Wheatstone, viz.,

THE DIFFERENTIAL RESISTANCE MEASURER.

This instrument (better known by the name of Wheatstone's Bridge) was also constructed by Mr. Becker on the largest scale (Fig. 77). The board is 8 ft. long and 2 ft. 8 in. wide; the lozenge-shaped brass plates are 1½ in. wide. There are four *breaks with* binding-screws, and, by using bobbins upon which *the B. A. unit of German* silver wire was wound, the audience was made to *understand that* each bobbin represented a mile of pure copper wire, No. 16.

In the lecture-room, the resistance of two miles, as compared with one mile, of wire was clearly demonstrated. The resistance of two equal pieces of wire was shown to be altered by heat, obtained by merely touching one with the hand or putting it into the mouth.

Three tubs of water, containing three lengths of wire, measuring one hundred yards, were supposed to represent the Atlantic Telegraph Cable, and were balanced against a resistance coil. Directly the miniature cable was broken, the spot of light became violently agitated when the key was pressed down; and it was shown that, time permitting, the lecturer could discover not only that the wire *was* broken, but *where* it was broken—just as they can now discover any place thousands of miles from England, and deep down in the bed of the Atlantic Ocean, where an accident may have happened to the cable; they can determine the precise spot, and, by sending a proper vessel with tackle, can pick up and reunite and repair the broken part, as they did in the recovery and resplicing of the old Atlantic Telegraph Cable.

The Differential Resistance Measurer is fully described by Wheatstone in the "Transactions of the Royal Society," 1843, Part II., p. 323.

For the sake of the young student, and considering also that the construction and principle of Wheatstone's bridge frequently form the subject of an examination question, the writer gives the following diagrams and explanations, which he trusts will be found useful.

For the sake of simplicity, the brass bands and breaks only are shown.

The galvanometer is supposed to be resting in the middle of the board, the battery on the right, and the connecting key on the left.

FIG. 79.—DIAGRAM I.

For the sake of discussion, it is supposed that the current coming from the *battery,* B *a, is represented* by twelve parts: these, on arriving at P, split or *divide into equal parts;* six go in the direction A′, and six in the other, A.

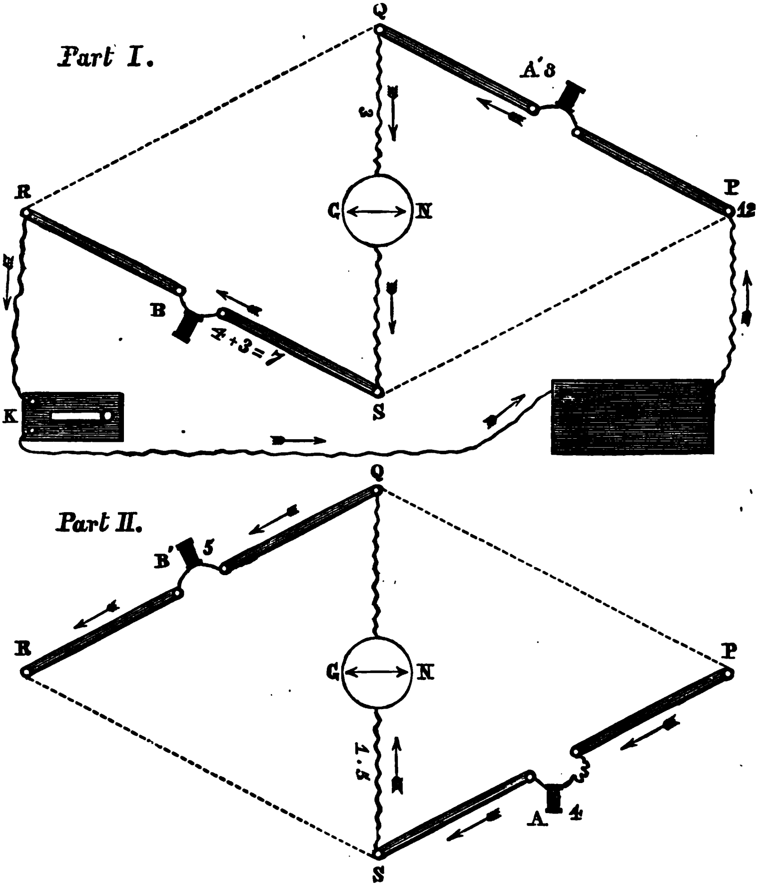


FIG. 80.—DIAGRAM II.

The two currents, represented by arrows, both pass through equal resistance coils, A' A, and the respective currents might pass direct to the key K (where contact is made or broken), and through that to the other pole of the battery; but the currents are partially arrested by the equal resistance coils, B' B, and a portion of the currents is forced into or diverted into the galvanometer, G N.

The use of the coils, or any other resisting matter, on the other side of the galvanometer is to force, or rather gently to impel, a part of the current into the galvanometer; because, if this was not done, the deflection would be so *small it might be barely* perceptible.

Let us say, for the sake of discussion, that two parts pass to the galvano-

meter from Q, and two parts from S; such currents, coming in opposite directions, must oppose each other's progress through the galvanometer, and therefore the needle of the latter does not move.

We have only now to suppose that 4+2=6 proceed from Q′ to R, and 4+2=6 by S to R; the two added together make 12, the original quantity started with, which proceeds through the key and connecting wire to the other pole of the battery, B *a*.

The second diagram (Fig. 80) consists of two parts, viz., Part I. and Part II., and it is recommended that the latter be traced on tracing-paper by the student, who can place it upon Part I. The current again is represented by twelve parts. The resistance of the coil at A′, Part I., being less than A, Part II., the greater part of the current, say 8 A′ parts, go through the former, and 4 A through the latter, consisting of a piece of copper wire and a resistance coil; therefore, returning to Part I., the current going by A′, through Q′, to G N, the galvanometer needle, forms at the point Q′ a greater partial current (say three parts) than the current going by A, Part II., which divides at S, and is represented by, say, one and a half parts; therefore, the current that deflects the galvanometer is the greater current going by Q′, Part I., and marked 3; consequently it amounts in imagination to a struggle between the current going by Q′, Part I., represented by three parts, and the current going by S, Part II., or one and a half parts. The issue cannot be doubtful; the greater current, three, overcomes the lesser, one and a half. In Part I., 4+3=7 go by B; and in Part II., five go by B; and, if the two are added together, they again make the twelve parts, which, as before, travel through the key and connecting wire to the other pole of the battery, B *a*.

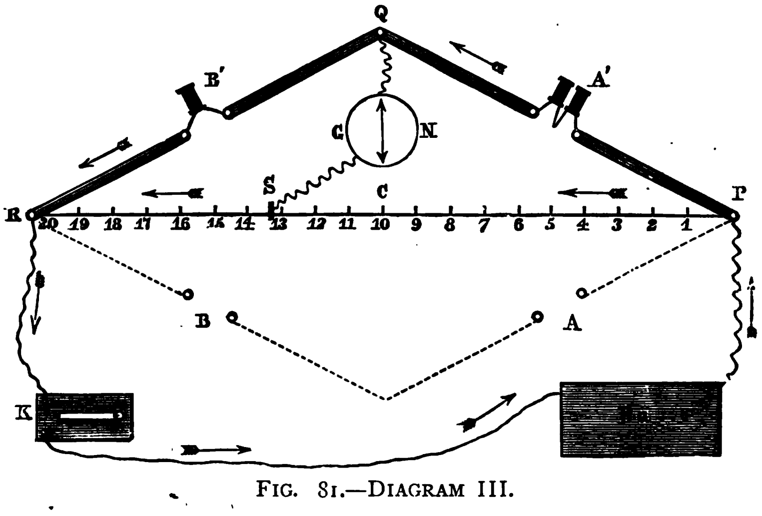


FIG. 81.—DIAGRAM III.

This diagram (Fig. 81) explains the use of the "bridge" for comparing the *conductivity or resistance* of wires of different metals or different lengths of

the same wire. The lower part, A B, of the bridge, marked in dotted lines, is not required, its place being filled by a long German silver wire stretched from P to R, and provided with a scale divided, say, into twenty parts; on this wire slides a clip or binding-screw, S, and this is connected with one of the galvanometer-screws, the other screw of the galvanometer being connected with Q.

In this case, we are to suppose it is being used to ascertain the relative lengths of wire of the same metal, diameter, and conductivity. The clip, S, has been moved from the centre, C, to No. 13·334 on the scale painted below the wire, P R. The clip has been moved to 13·334, or until the galvanometer is at rest; this quantity, 13·334, is double that of R S, therefore the resistance at B′ is shown to be half the resistance at A′, because A′ has two coils, or two miles of wire, and B′ one mile; so that it is shown, without any previous knowledge of the absolute length of the two coils at A′ (the wire under examination), that it is double the length of the known quantity, one mile at B′, because the scale from R to S is 6·666, and that from P to S 13·334, and, if one is added to the other, thev make up the whole scale of 20.

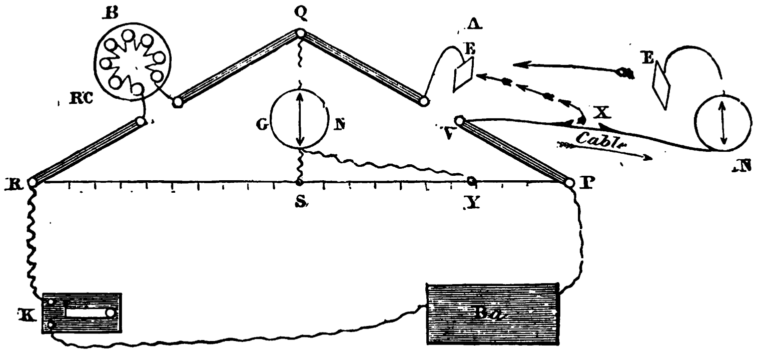


FIG. 82.—DIAGRAM IV.

The object of the diagram (Fig. 82) is to explain the use of the arrangement (Fig. 81, Diagram III.), for the purpose of discovering the exact point under the Atlantic Ocean where the cable is supposed to be broken. As before, the lower part of the bridge is not used: the wire, P R, and scale are employed in this experiment.

The current, starting from the battery B *a*, arrives at P, where it splits into two currents: one passes along the wire, P R, and the other is supposed to go through the cable marked "Cable," at A′. The galvanometer needle is brought to rest by the balancing of the resistance of the cable by various resistance coils, R C, at B′: this supposes the cable to be perfect when the clip, S, is in the centre.

Let us now imagine that the cable is broken at X. The spot of light from Thompson's galvanometer needle (see Fig. 77, p. 74) is now violently *agitated or deflected when* the contact is made with the battery, because the *current, instead of travelling* through the whole length of the cable, takes a

short cut, as shown by the short arrows; its path or resistance is decreased enormously, and it no longer balances with the resistance coils, R C, at B′. To make it balance, the clip, S, is moved to Y; then by measuring the distance from R to Y, and the distance from P to Y, on the graduated scale, it is easy by a calculation to discover the distance from the shore where the rupture has taken place. V is supposed to be Valentia, and N, Newfoundland; E and E are the wires which go out into the sea, and are usually designated as "earth-plates" in all diagrams, to prevent confusion.

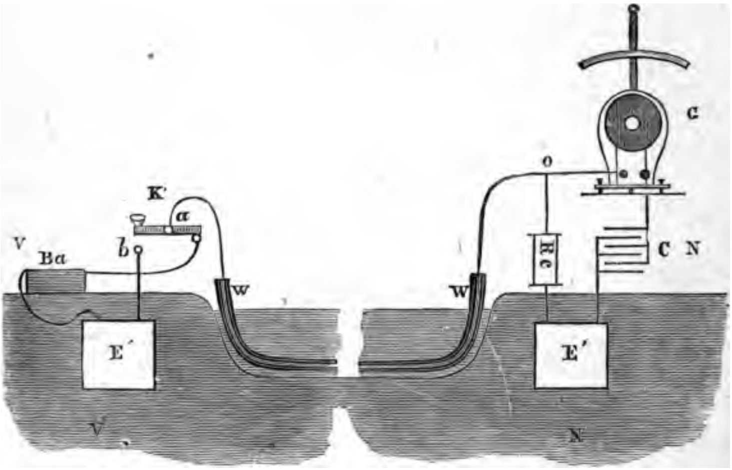


FIG. 83.—DIAGRAM V.

The last diagram (Fig. 83) is intended to give the student a general notion of the apparatus required to send the electric current, *i.e.*, "messages," through the great Atlantic Telegraph cable.

We commence at V, Valentia. B *a* is the battery connected with the earth-plate, E′; K is the key connected with the other pole of the battery at *a;* E′ is the earth-plate (not really so, as it is a wire running into the sea); W W represents the cable under the water, passing across to N, Newfoundland, where the electric force enters the condenser, C (an arrangement of mica plates and tin-foil, fulfilling the same office as a Leyden battery), through the galvanometer, G; R *c* is a large resistance coil connected with the earth-plate and also with the cable at the point O: one side of the condenser is also connected with the earth-plate.

The course of the electric force is certainly tortuous, but, once studied and understood, is one of the most simple and beautiful processes of reasoning that the lover of science can desire.

As the cable is now represented in the diagram, a current can pass from the *battery, B a, through* K, at the point *a*, to the cable, and through it to the point *O, where the greater part* will pass through G, the galvanometer, into the condenser, *C; the other part* of the current passing from O, through the resistance

coil, R c, to the earth-plate E′, and from E′ back to the battery B a, through the other earth-plate, E′.

The current, in passing through the galvanometer, deflects it until it has fully charged the condenser, when it returns to zero.

The signals are sent by pressing down the key, K, and so putting the cable to earth as the key is pressed down upon b, which is connected with the earth-plate E′. The consequence is that the electrical tension of the cable falls below that of the condenser; a current then flows from the condenser, C, through the galvanometer, G (deflecting it, the deflection being the signal), to the cable, in order to establish the equilibrium of the latter.

At a banquet given, at the Polytechnic, by the chairman and directors of the Royal Polytechnic to Sir Charles Wheatstone and the scientific men of London, at which many noblemen and gentlemen assisted, the writer was enabled, by the kindness of the various telegraphic companies, to bring the wires into the Polytechnic; and, whilst the company were seated, the following message was sent to the President of the United States, and his answer received, as reprinted in "The Evening Post," New York, Wednesday, January 1, 1868:

"CABLE NEWS.—*Advices from Europe to December* 30, 1867.—The following advices by the Atlantic Telegraph have been received:

"INTERNATIONAL COURTESIES.

"*London, December* 24.—At a banquet given at the Royal Polytechnic on Saturday night last, in reply to the following sentiment from the Duke of Wellington and Sir Charles Wheatstone, a despatch from the President of the United States was read amid great enthusiasm. Not a little of the interest attaching to these despatches grows out of their rapid transmission:

"MESSAGE OF THE DUKE OF WELLINGTON TO THE PRESIDENT OF THE UNITED STATES.

"'*Royal Polytechnic, London, December* 21.—The Duke of Wellington, the directors and scientific guests now at the Royal Polytechnic, London, England, send their most respectful greeting to the President of the United States, their apology being that to the discoveries of science the intercourse between two great nations is indebted.'

"[The above message was 9 minutes 30 seconds in transit from London to Washington, as follows: London to Heart's Content, 4 minutes 30 seconds; Heart's Content to Plaister Cove, 1 minute 30 seconds; at Plaister Cove, 30 seconds; Plaister Cove to New York, 1 minute 30 seconds; New York to Washington, 1 minute 30 seconds.]

"REPLY.

"'*Washington, December* 21.

"'*Duke of Wellington, London:* I reciprocate the friendly salutation of the banqueting party at the Royal Polytechnic, and cordially agree with them in the sentiment that free and quick communication between governments and nations is an important agent in preserving peace and good understanding throughout the world, and advancing all the interests of civilization.

"'ANDREW JOHNSON.'

"The reply occupied 29 minutes in actual transmission. On the same evening, a message of twenty-two words was started from the Polytechnic *for Heart's Content* at exactly 9 p.m., and at 9.10 the reply of twenty-four *words was delivered.*"

The completion of the articles on LIGHT, HEAT, ELECTRICITY, and MAGNETISM, &c., cannot be better consummated than by a report, which appeared in the "Literary Gazette," of Faraday's lecture at the Royal Institution,

ON THE CONSERVATION OF FORCE.

"When we occupy ourselves with the dual forms of power, electricity and magnetism, we find great latitude of assumption: and necessarily so, for the powers become more and more complicated in their conditions. But still there is no apparent desire to let loose the force of the principle of conservation, even in those cases where the appearance and disappearance of force may seem most evident and striking. Electricity appears when there is consumption of no other force than that required for friction; we do not know how, but we search to know, not being willing to admit that the electric force can arise out of nothing. The two electricities are developed in equal proportions; and, having appeared, we may dispose variously of the influence of one upon successive portions of the other, causing many changes in relation, yet never able to make the sum of the force of one kind in the least degree exceed, or come short of, the sum of the other. In that necessity of equality we see another direct proof of the conservation of force in the midst of a thousand changes that require to be developed in their principles before we can consider this part of science as even moderately known to us. One assumption with regard to electricity is, that there is an electric fluid rendered evident by excitement in plus and minus proportions. Another assumption is, that there are two fluids of electricity, each particle of each repelling all particles like itself, and attracting all particles of the other kind always, and with a force proportionate to the inverse square of the distance, being so far analogous to the definition of gravity. This hypothesis is antagonistic to the law of the conservation of force, and open to all the objections that have been, or may be, made against the ordinary definition of gravity. Another assumption is, that each particle of the two electricities has a given amount of power, and can only attract contrary particles with the sum of that amount, acting upon each of two with only half the power it could, in like circumstances, exert upon one. But various as are the assumptions, the conservation of force, though wanting in the second, is, I think, intended to be included in all. I might repeat the same observations nearly in regard to magnetism,—whether it be assumed as a fluid or two fluids or electric currents—whether the external action be supposed to be action at a distance or dependent on an external condition and lines of force—still all are intended to admit the conservation of power as a principle to which the phenomena are subject. The principles of physical knowledge are now so far developed as to enable us not merely to define or describe the *known*, but to state reasonable expectations regarding the *unknown;* and I think the principle of the conservation of force may greatly aid experimental philosophers in that duty to science which consists in the enunciation of problems to be solved. It will lead us, in any case where the force remaining unchanged in form is altered in direction only, to look for the new disposition of the force, as in the cases of magnetism, static electricity, and perhaps gravity, and to ascertain that as a whole it remains unchanged in amount; or, if the original force disappear, either altogether or in part, it will lead us to look for the new condition or form of force which should result, and to develop its equivalency to the force that has disappeared. Likewise, when force is developed, it will cause us to consider the previously

existing equivalent to the force so appearing; and many such cases there are in chemical action. When force disappears, as in the electric or magnetic induction after more or less discharge, or that of gravity with an increasing distance, it will suggest a research as to whether the equivalent change is one within the apparently acting bodies or one *external* (in part) to them. It will also raise up inquiry as to the nature of the internal or external state, both before the change and after. If supposed to be external, it will suggest the necessity of a physical process, by which the power is communicated from body to body; and in the case of external action, will lead to the inquiry whether, in any case, there can be truly action at a distance, or whether the ether, or some other medium, is not necessarily present. We are not permitted as yet to see the nature of the source of physical power, but we are allowed to see much of the consistency existing amongst the various forms in which it is presented to us. Thus if, in static electricity, we consider an act of induction, we can perceive the consistency of all other like acts of induction with it. If we then take an electric current, and compare it with this inductive effect, we see their relation and consistency. In the same manner we have arrived at a knowledge of the consistency of magnetism with electricity, and also of chemical action and of heat with all the former; and if we see not the consistency between gravitation with any of these forms of force, I am strongly of the mind that it is because of our ignorance only. How imperfect would our idea of an electric current now be if we were to leave out of sight its origin, its static and dynamic induction, its magnetic influence, its chemical and heating effects? or our idea of any one of these results, if we left any of the others unregarded? That there should be a power of gravitation existing by itself, having *no relation to the other natural powers, and no respect to the law of the conservation of force*, is as little likely as that there should be a principle of levity as well as of gravity. Gravity may be only the residual part of the other forces of nature, as Mossotti has tried to show; but that it should fall out from the law of all other force, and should be outside the reach either of further experiment or philosophical conclusions, is not probable. So we must strive to learn more of this outstanding power, and endeavour to avoid any definition of it which is incompatible with the principles of force generally, for all the phenomena of nature lead us to believe that the great and governing law is one. I would much rather incline to believe that bodies affecting each other by gravitation act by lines of force of definite amount (somewhat in the manner of magnetic or electric induction, though without polarity), or by an ether pervading all parts of space, than admit that the conservation of force can be dispensed with. It may be supposed that one who has little or no mathematical knowledge should hardly assume a right to judge of the generality and force of a principle such as that which forms the subject of these remarks. My apology is this: I do not perceive that a mathematical mind, simply as such, has any advantage over an equally acute mind not mathematical in perceiving the nature and power of a natural principle of action. It cannot of itself introduce the knowledge of any new principle. Dealing with any and every amount of static electricity, the mathematical mind can and has balanced and adjusted them with wonderful advantage, and has foretold results which the experimentalist can do no more than verify. But it could not discover dynamic electricity, nor electro-magnetism, nor *magneto-electricity*, nor even suggest them; though, when once discovered by *the experimentalist*, it can take them up with extreme facility. So in respec

of the force of gravitation, it has calculated the results of the power in such a wonderful manner as to trace the known planets through their courses and perturbations, and in so doing has *discovered* a planet before unknown; but there may be results of the gravitating force of other kinds than attraction inversely as the square of the distance, of which it knows nothing, can discover nothing, and can neither assert nor deny their possibility or occurrence. Under these circumstances, a principle, which may be accepted as equally strict with mathematical knowledge, comprehensible without it, applicable by all in their philosophical logic, whatever form that may take, and, above all, suggestive, encouraging, and instructive to the mind of the experimentalist, should be the more earnestly employed and the more frequently resorted to when we are labouring either to discover new regions of science, or to map out and develop those which are known into one harmonious whole; and if in such strivings we, whilst applying the principle of conservation, see but imperfectly, still we should endeavour to see, for even an obscure and distorted vision is better than none. Let us, if we can, discover a new thing in *any shape;* the true appearance and character will be easily developed afterwards. Some are much surprised that I should, as they think, venture to oppose the conclusions of Newton: but here there is a mistake. I do not oppose Newton on any point; it is rather those who sustain the idea of action at a distance that contradict him. Doubtful as I ought to be of myself, I am certainly very glad to feel that my convictions are in accordance with his conclusions. At the same time, those who occupy themselves with such matters ought not to depend altogether upon authority, but should find reason within themselves, after careful thought and consideration, to use, and abide by, their own judgment. Newton himself, whilst referring to those who were judging his views, speaks of such as are competent to form an opinion in such matters, and makes a strong distinction between them and those who were incompetent for the case. But, after all, the principle of the conservation of force may by some be denied. Well, then, if it be unfounded even in its application to the smallest part of the science of force, the proof must be within our reach, for all physical science is so. In that case, discoveries as large or larger than any yet made may be anticipated. I do not resist the search for them, for no one can do harm, but only good, who works with an earnest and truthful spirit in such a direction. But let us not admit the destruction or creation of force without clear and constant proof. Just as the chemist owes all the perfection of his science to his dependence on the certainty of gravitation applied by the balance, so may the physical philosopher expect to find the greatest security and the utmost aid in the principle of the conservation of force. All that we have that is good and safe, as the steam-engine, the electric telegraph, &c., witness to that principle,—it would require a perpetual motion, a fire without heat, heat without a source, action without reaction, cause without effect, or effect without a cause, to displace it from its rank as a law of nature."

INDEX.

MAGNETISM.

MAGNETISM—*continued.*